



CHE 5201 - HAZARDOUS WASTE MANAGEMENT

Hazardous waste treatment and disposal; hazardous waste identification, basic properties of hazardous waste, classification of hazardous waste, hazardous waste generation and characteristics, transportation and storage of hazardous waste, physical, chemical and biological treatment, thermal treatment and energy recovery, stabilisation and solidification and land disposal of hazardous waste, alternative hazardous waste management programs.

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1. INTRODUCTION

Developing countries often experience great difficulty in managing Hazardous Waste (HW). Interim solutions may be required to bring such problem under immediate control whilst more permanent facilities are developed. Even in the long term, there will be a need for solutions which are compatible with the limited resources available. In several European countries, the different political and legal systems have resulted in strategies that differ in some important details. Some countries have emphasized on the establishment of treatment facilities, without having intervened so far on the waste minimization field.

The HW management issue in many countries shows marked differences to those experienced in industrialized nations. Even where problems appear to be similar, the lack of resources and may require not to be stick to solutions now being advocated in the West. In this sense, the evolutionary process that has occurred in many countries may be a more useful and achievable model to be adopted by other developing countries, than to aim for an instant transplant of technically and administratively sophisticated controls that are not even standard in many OECD countries. Once infrastructure, resources and public awareness raise to a higher level (perhaps as a result of the first interim measures), the progression to more complex control systems becomes easier.

The case studies show that, even under adverse circumstances, several countries have been able to resolve certain critical problems. Often, the lack of adequate knowledge on the existed problem, is a greater handicap than the lack of resources. The latter point brings out a fundamental controversy concerning the need to analyse the problem and the need to take early action. It should be noted though, that without a reasonable idea of what the dimensions of the problem are, any action is a shot in the dark.

An unresolved, and perhaps irresolvable issue, is that of the adopted standards. Interim solutions are rapid but leaving a number of sectors unaddressed. More comprehensive solutions achieve better results but need more time, resources and expertise while are not able to evolve as circumstances change. In this regard, it may be more appropriate to assist and not to advise those who need to make the decisions. Finally, outside technical expertise is no substitute for good awareness and clear objectives at a local level [Wilson et al., 1990].

Dealing with the increasing amount of the generated HW worldwide has been one of the most raging issues during the last three decades. HW generation is not only limited to the developed countries, but also a major headache for the rapidly Developing Countries (DCs) of Asia like China, India as well as for underdeveloped countries.

Safe management of HW is becoming a major problem in many countries around the world. While there is no doubt that life expectancy and quality of life has increased during the past decade, it has also resulted in the production of variety of wastes, which are hazardous for mankind and the environment. Past practices of HW management have resulted in tens of thousands of contaminated sites. The global cost of restoring these sites could add up to vast amounts of money. In addition, we are facing the cost of dealing with current and future production of HW in such a way that they do not impair our environment or human health currently or in the future. The only difference among different countries (developed, developing and undeveloped) is that the level of awareness is much higher in the developed nations than in the DC. Furthermore, the characteristics, type and quantity of the generated HW vary depending on the level of development.

Ironically, waste was not a problem for the environment when the society was primitive and uncivilized. However, waste has become a problem for the civilized society. Earlier societies mainly generated 'natural wastes' containing more organic materials which were 'biodegradable' and non-hazardous. Industrial products were composed of relatively limited number of materials from the natural resources, many of them biological in origin and hence biodegradable. Nowadays, based on the technological development, a new category of



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'synthetic materials' has entered the market. The wastes generated from such materials revealed by technology such as semiconductors, optical fibres, new class of ceramics, and composites cannot be easily decomposed in nature and hence their safe disposal creates extraordinary technical, health, environmental, economic, political and social problems.

In this direction, most of the DC have already established HW management systems which, while not foolproof or problem-free, largely treat and dispose of the wastes in an environmentally sound manner. Waste minimisation measures are currently part of the waste management policy in developed countries, while developing economies have implemented waste minimisation programmes at a much mature stage. There is a number of countries, such as Russia, China and India, which have a well-established industrial areas but without having yet developed their HW management system to the same extent as other countries. Newly industrialising countries, which had treated small quantities of HW in the past, are now facing the need to manage larger quantities of more diverse materials. This happens because of the type of their industries which are HW-intensive, such as oil refining, petrochemicals, pharmaceuticals manufacture and metal fabrication.

The category of HW includes waste (solid, liquid, sludge or gaseous) containing toxic chemicals, radioactive substances and infectious materials that pose potential risk to human health and environment. In the smaller and less industrial developing economies, the above waste are often derived from the import of hazardous chemicals and other products from more developed countries. HW is mostly generated by mining and metallurgical industries, chemical and pharmaceutical industries; leather, rubber and textile industries; glasses and ceramic industries; electroplating and electrical construction industries; wood, paper pulp and furniture industries. A few examples of HW include oils from transportation; redundant pesticides from agriculture; chemical wastes from commerce; acids and lead from recycling motor batteries; and acids, alkalis and organic solutions from industrial cleaning, healthcare wastes, and a variety of wastes from small scale or 'cottage' industries, such as tanneries, print shops, textile dyeing and electroplating workshops.

A big problem however, lies in determining the actual quantity of HW annually generated worldwide because of the inconsistency of released data by reporting countries and overseas body as well as the lack of correct data in many of the developing and third world countries. For example, the total untreated HW annually generated in China varies from as high as 30 million tons (foreign bodies and agencies) to as low as 2 to 5 million tons [Adeleke, 2002]. In addition, a major difference lies in the definition of what constitutes a HW. In the US prior to 1997, the annually generated HW was often over 200 million tons which made it look astronomical compared to other OECD countries. This is because over 90% of the reported HW is wastewater, which is not often included in the calculations for other countries. After the US EPA changing the reporting requirement the annually HW volume is calculated about 40 million tons [EPA, 2001].

The dynamics between evolution of a regulatory program and the development of treatment and disposal capacity for HW is very complex. Without stringent regulations and enforcement, there is little incentive to develop (or use) state-of-art HW disposal facilities. On the other hand, without such facilities, it is difficult to comply with stringent management requirements. When a regulatory program precedes infrastructure, countries must take interim measures – such as storage, co-disposal, or export – to dispose of its HW [Probst et al., 1999]. In general, among the developed countries, the major stages in developing a program can be summarized as follows [Adeleke, 2002]:

- Identifying the problem and enacting legislation
- Designating a lead agency
- Promulgating rules and regulations
- Developing treatment and disposal capacity
- Creating a mature compliance enforcement program.



2. DEFINITION OF HAZARDOUS WASTE

The HW effects on both the environment and public health are related to “fires and explosions”. The early history is full of cases where sites burned and/or exploded, realising huge amounts of heat energy, toxic, vapours and particulates while many of these cases were confirmed as arsons. In some cases, sites emitted toxic vapours without fire or explosion. Such events were often spectacular, frequently hazardous to human health and/or safety and always frightening to the public. However, the exposures tended to be short-lived (i.e. a few hours or days) with a relatively small number of acute health effects, fewer fatalities and even fewer cases of chronic health effects [Blackman, 2001].

2.1. Hazardous Waste characteristics

The definition of HW varies from one country to another. The Resource Conservation and Recovery Act (RCRA) HW is a waste that appears on one of the four HW lists (F-list, K-list, P-list, or U-list), or exhibits at least one of four characteristics-ignitability, corrosivity, reactivity, or toxicity [EPA (a)].

F-list (non-specific source wastes). This list identifies wastes from common manufacturing and industrial processes, such as solvents that have been used in cleaning or degreasing operations. Because the processes producing these wastes can occur in different sectors of industry, the F-listed wastes are known as wastes from non-specific sources.

K-list (source-specific wastes). This list includes certain wastes from specific industries, such as petroleum refining or pesticide manufacturing. Certain sludges and wastewaters from treatment and production processes in these industries are examples of source-specific wastes.

P-list and the U-list (discarded commercial chemical products). These lists include specific commercial chemical products in an unused form. Some pesticides and some pharmaceutical products become HW when discarded.

Ignitable wastes can create fires under certain conditions, are spontaneously combustible, or have a flash point less than 60 °C (140 °F). Examples include waste oils and used solvents.

Corrosive wastes are acids or bases (pH less than or equal to 2, or greater than or equal to 12.5) that are capable of corroding metal containers, such as storage tanks, drums, and barrels. Battery acid is an example.

Reactive wastes are unstable under "normal" conditions. They can cause explosions, toxic fumes, gases, or vapors when heated, compressed, or mixed with water. Examples include lithium-sulfur batteries and explosives.

Toxic wastes are harmful or fatal when ingested or absorbed (e.g., containing mercury, lead, etc.). When toxic wastes are land disposed, contaminated liquid may leach from the waste and pollute ground water. Toxicity is defined through a laboratory procedure called the Toxicity Characteristic Leaching Procedure (TCLP). The TCLP helps in identifying wastes likely to leach concentrations of contaminants that may be harmful to human health or the environment (Table 1).



Table 1. Hazardous Chemicals and Their Effects [OSHA, 2001].

Hazardous Chemicals	Adverse Health Effects
Benzene (crude oils high in BTEX, benzene, toluene, ethylbenzene, and xylene)	Irritation to eyes, skin, and respiratory system; dizziness; rapid heart rate; headaches; tremors; confusion; unconsciousness; anemia; cancer
Benzo(a)pyrene (a polycyclic aromatic hydrocarbon reproductive [see below], formed when oil or gasoline burns)	Irritation to eyes and skin, cancer, possible effects
Carbon dioxide (inerting atmosphere, byproduct of combustion)	Dizziness, headaches, elevated blood pressure, rapid heart rate, loss of consciousness asphyxiation, coma
Carbon monoxide (byproduct of combustion) Irritation to eyes, skin, and Respiratory	Dizziness, confusion, headaches, nausea, weakness, loss of consciousness, asphyxiation, coma
Ethyl benzene (high in gasoline)	Irritation to eyes, skin, and respiratory system; loss of consciousness; asphyxiation; nervous system effects
Hydrogen sulfide (oils high in sulfur, decaying plants and animals)	Irritation to eyes, skin, and respiratory system; dizziness; drowsiness; cough; headaches; nervous system effects
Methyl tert-butyl ether (MTBE) (octane booster and clean air additive for gasoline, or pure MTBE)	Irritation to eyes, skin, and respiratory system; headaches; nausea; dizziness; confusion; fatigue; weakness; nervous system, liver, and kidney
Polycyclic aromatic hydrocarbons (PAHs) (occur in crude oil, and formed during burning of oil)	Irritation to eyes and skin, cancer, possible reproductive effects, immune system effects
Sulfuric acid (byproduct of combustion of sour petroleum product)	Irritation to eyes, skin, teeth, and upper respiratory system; severe tissue burns; Cancer
Toluene (high BTEX crude oils)	Irritation to eyes, skin, respiratory system; fatigue; confusion; dizziness; headaches; memory loss; nausea; nervous system, liver, and kidney effects
Xylenes (high BTEX crude oils)	Irritation to eyes, skin, respiratory system; dizziness; confusion; change in sense of balance; nervous system gastrointestinal system, liver, kidney, and blood effects

2.2. Hazardous Waste categories

HW arise from a very large number of sources in a modern society, ranging from heavy industry to commerce, agriculture, medical care and even the ordinary home. The earlier view that HW derive from industrial procedures is out of date. Although industry remains the biggest single producer of chemical residues, the other smaller sources have the problem of being far more dispersed, thus creating a problem of widespread low-level contamination. While chemical producers can reasonably be expected to understand the nature of the residues they produce, other generators, especially small businesses and households, often do not know or understand the hazards of the materials they discard. For the introduction and implementation of HW controls, as well as to enable the provision of appropriate facilities, it is necessary to obtain information about the amounts and types of the generated waste.



There are many types of HW that pose varying degrees of danger to public safety and environmental health. Disposal of these materials can be challenging and often needs to be handled by professionals. According to the industrial development the categories of HW per country vary.

The quantity of HW is not the sole concern: a small quantity of chemically difficult HW may be more problematic than a large quantity of a relatively simple chemical. Often, when beginning a new HW control regime, authorities first target the small number of generators of large amounts of HW such as those from the industries listed. In developing economies the main HW volumes may arise from large numbers of small generators, and therefore these are the main target for control measures. Such small generators include:

- General engineering and manufacturing industries
- Machinery and vehicle manufacture
- Electrical and electronics industry
- Wood preservation

These kinds of small and medium sized industries are numerous and may produce wastes which are chemically complex in nature.

Figure 1 presents the 3 basic HW categories in DCs (i.e. Bangkok) and Table 2 estimates the production of hazardous industrial waste in Thailand. A full analysis of each HW category worldwide is presented in the following chapters.

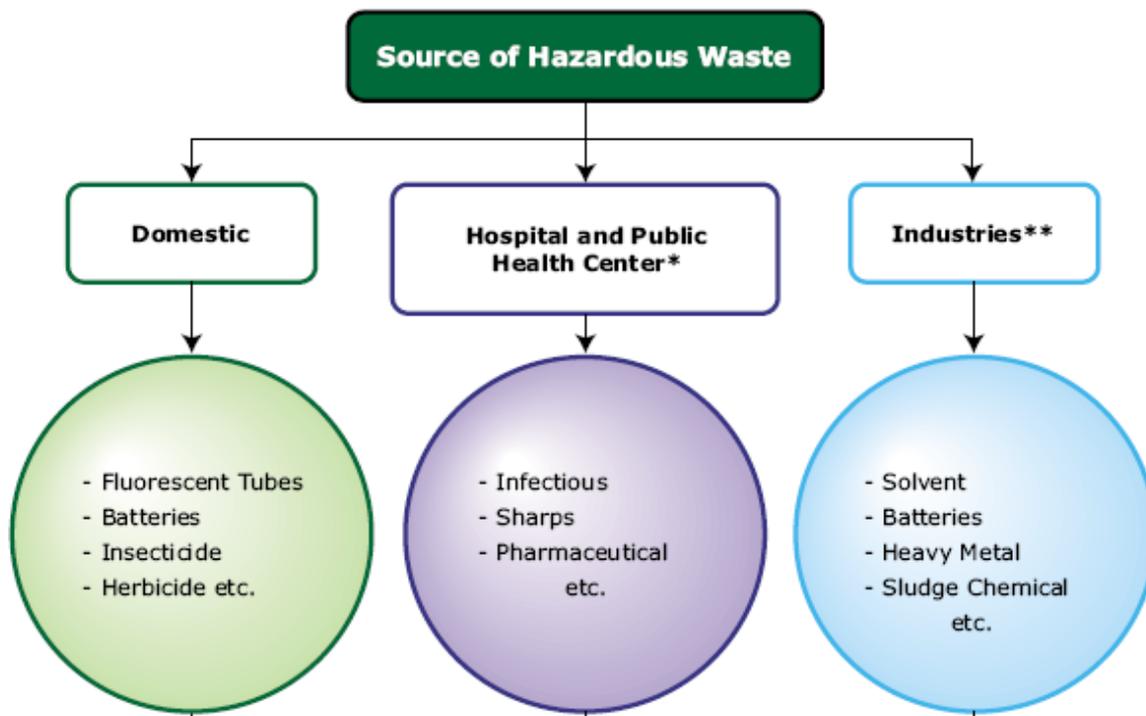


Figure 1. Hazardous Waste Management Process in Bangkok [UNEP, 2001].



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Table 2. Estimates of production of hazardous waste in Thailand (in thousands of tonnes) [Lohwongwatana et al., 1990].

Estimate	Total	Metals	Tannery	Number of factories
Whole Kingdom, 1986	1200	820	-	-
Whole Kingdom, 2001	6000	440	-	-
Greater Bangkok, 1983	150	90	4	682
Greater Bangkok, 2000	300	180	8	-
Samut Prakarn Industrial area, 1986	25	12	10	1400
Siam Control Co. (September 1988-May 1989)	8.3	8.1	-	75

2.2.1. Industrial hazardous waste

Many cleaners and solvents used in industrial and commercial processes become HW after their use. Industrial solid waste - which may be solid, liquid or gases held in containers - is divided into hazardous and non-HW. HW may result from manufacturing or other industrial processes. Certain commercial products such as cleaning fluids, paints or pesticides discarded by commercial establishments or individuals can also be defined as HW. Table 3 illustrates HW produced by basic industries.

2.2.2. Hazardous elements in municipal waste

Household Hazardous Waste (HHW) is the term for common household chemicals and substances for which the owner no longer has a use. Improper disposal of HHW can include pouring them down the drain, on the ground, into storm sewers, or in some cases putting them out with the trash. The dangers of such disposal methods might not be immediately obvious, but improper disposal of these wastes can pollute the environment and pose a threat to human health [EPA (b)]. Certain types of HHW have the potential to cause physical injury to sanitation workers, contaminate septic tanks or wastewater treatment systems if poured down drains or toilets, and present hazards to children and pets if left around the house. Law allows disposal of HHW in the trash. However, many communities worldwide have collection programs for HHW to reduce the potential harm posed by these chemicals.

Below are presented two HW categories which are often found in HHW.

2.2.2.1. Electronic Waste

Many electric and electronic products contain trace amounts of hazardous materials that can pose problems if incinerated or disposed of in a landfill. Computers contain many components that fall into this category, including CPUs, CRT monitors and printed circuit boards. Their widespread use and unregulated disposal make them a real contributor to the overall HW problem. The WEEE management issue is one of the greatest challenges facing the waste industry today. We know that when it comes to expensive, electrical equipment, repair is better than disposal. The toxicity and complexity of these types of product make them notoriously difficult to recycle and sadly the rate of production is far greater than our ability or willingness to recycle them.



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The result is a violation of human rights with the developed world sending piles of WEEE to DC to be dumped. As many of these shipments being sent illegally it is very difficult to monitor the numbers involved. In Nigeria has become a big problem with much of the waste arriving in the country disguised as second-hand goods. Large environmental organisations such as Greenpeace are championing the case. A report in 2007 by Basel action Network pointed out that about 500 containers with 400,000 second-hand computers were unloaded every month in Lagos. This waste can contain substances such as lead, cadmium and mercury which are an environmental and health hazard [WMW, 2010].

2.2.2.2. *Universal Waste*

Another category of HW is designated as universal waste. This waste is generated from a large variety of sources and consists of products that serve both commercial and personal use. Two of the prime examples of universal waste are batteries and light bulbs. Used throughout society in great quantities, disposal of batteries and other forms of universal waste cannot be as closely monitored or controlled as industrial waste. Commonly just thrown out with the trash, these wastes make their way into landfills and incinerators where their toxic components are released into the environment.

2.2.3. Healthcare waste

Waste generated by healthcare activities includes a broad range of materials, from used needles and syringes to soiled dressings, body parts, diagnostic samples, blood, chemicals, pharmaceuticals, medical devices and radioactive materials. Poor management of health care waste potentially exposes health care workers, waste handlers, patients and the community at large to infection, toxic effects and injuries, and risks polluting the environment. It is essential that all medical waste materials are segregated at the point of generation, appropriately treated and disposed of safely.

From the total of wastes generated by health-care activities, almost 80% are general waste comparable to domestic waste. The remaining approximate 20% of wastes are considered hazardous materials that may be infectious, toxic or radioactive.

The wastes and by-products cover a diverse range of materials, as the following list illustrates (percentages are approximate values) [WHO]:

Table 3. Examples of hazardous waste produced by basic industries [EPA, 1985] and [TCPS].

Industry	Waste produced
Chemical manufacturing	Spent solvents and still bottoms
	Ignitable waste not otherwise specified
	Strong acid/alkaline waste
	Other reactive waste
	Emission control dusts and sludges
	Spent catalysts
	Ignitable paint waste
Construction	Ignitable waste not otherwise specified
	Spent solvents



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Industry	Waste produced
	Strong acid/alkaline waste
Metal manufacturing	Spent solvents and still bottoms Strong acid/alkaline waste Spent plating waste Heavy metal wastewater sludges Cyanide wastes Ignitable wastes not otherwise specified Other reactive waste Used oils
Petroleum Refining Industry	Wastewater containing Benzene & other Hydrocarbons Sludge from refining process
Leather Products Manufacturing	Toluene and benzene
Paper industry	Halogenated solvents Corrosive wastes Paint wastes Solvents
Printing Industry	Heavy metal solutions Waste Inks Solvents Ink sludges containing Heavy metals

- Infectious wastes -- cultures and stocks of infectious agents, wastes from infected patients, wastes contaminated with blood and its derivatives, discarded diagnostic samples, infected animals from laboratories, and contaminated materials (swabs, bandages) and equipment (disposable medical devices etc.); and
- Anatomic - recognizable body parts and animal carcasses.

Infectious and anatomic wastes together represent the majority of the HW, up to 15% of the total waste from health-care activities.

Sharps -- syringes, disposable scalpels and blades etc. They represent about 1% of the total waste from health-care activities.

Chemicals (solvents and disinfectants, etc) and pharmaceuticals (expired, unused, and contaminated; whether the drugs themselves (sometimes toxic and powerful chemicals) or their metabolites, vaccines and sera) amount to about 3% of waste from health-care activities.



Genotoxic waste (highly hazardous, mutagenic, teratogenic¹ or carcinogenic, such as cytotoxic drugs used in cancer treatment and their metabolites) and radioactive matter, such as glassware contaminated with radioactive diagnostic material or radio-therapeutic materials and wastes with high heavy metal content, such as broken mercury thermometers, represent about 1% of the total waste from health-care activities.

The major sources of health-care waste are hospitals and other health-care establishments, laboratories and research centres, mortuary and autopsy centres, animal research and testing laboratories, blood banks and collection services, and nursing homes for the elderly.

The generation of healthcare waste is closely related with:

- National income level (c.f. Table 4)
- Number of healthcare institutions
- Diversity of healthcare institutions/clinics
- Number of beds per healthcare institution

Table 4. Health-care Waste Generation (according to national income level) [Karaca, 2005].

National income level	Annual waste generation (kg/head of population)
High-income countries	
-all health-care waste	1.1-12.0
-hazardous health-care waste	0.4-5.50
Middle-income countries	
- all health-care waste	0.8-6.0
- hazardous health-care waste	0.3-0.4
Low-income countries	
-all health-care waste	0.5-3.0

2.2.4. Nuclear Waste

Waste generated from nuclear power plants and nuclear weapon technology is arguably the most dangerous created by society. The dangers associated with nuclear waste are compounded by the extremely long half life of radioactive materials, during which they maintain their hazardous properties. Dangers from nuclear waste include both immediate health risks and long-term risks related to increases in cancer and birth defects. There are also safety issues around nuclear waste as certain types can be used as weapons and need to be stringently controlled.

2.2.5. Construction Waste

Waste from construction sites can be hazardous. Asbestos tiles and insulation, lead pipes and certain chemicals used in maintenance all fall into this category. The construction industry needs to be aware of these hazards and vigilant in their safe disposal. EPA guidelines again regulate and educate the industry on the disposal of their waste.

3. ENVIRONMENTAL IMPACTS AND HEALTH RISKS



The health risks and environmental impacts arising from HW are common to all countries, since the potentially health-threatening components within each waste type are similar. However, the actual risks posed vary widely, as they can be greatly reduced by good operational practices, storage methods, personal hygiene, enforcement of regulations and quality of management.

The country's overall level of income provides a guide to the level of public health and environmental protection expenditure available. In middle and lower-income countries, the stockpiling of industrial wastes is commonplace at factories due to a shortage of waste treatment facilities and a lack of waste management programmes. Unauthorised HW dumps may contain a cocktail of hazardous materials such as heavy metals. Considerable volumes of HW may accumulate in such open dumps and these can affect water supplies and create demonstrable environmental hazards. It is important to take early steps to provide licensed treatment and disposal capacity which matches waste generation, if the risks from HW are to be reduced.

Public concern about the possible impacts associated with HW often evolves with a general increase in industrial activity in a country or city, and by analogy with the effects of chemicals mismanagement in the work place and on the environment. It may be brought to the fore when facilities for treating HW are proposed. The NIMBY (Not- In- My- Back- Yard) syndrome is an understandable reaction, particularly where old dumps have caused obvious pollution, but it can result in proposed facilities failing to go ahead, leaving wastes no proper treatment or disposal routes. Ironically then, public concern can exacerbate environmental and health risks from HW.

For most environmental exposures to chemicals, except for accidentally high concentration levels, the quantifiable epidemiological evidence on health effects is poor and the links between the two are weak. The epidemiological evidence on the health effect arising from both municipal and HW management is no different. There have been a number of attempts to investigate a causal link between wastes and health effects but the results to date have been far from conclusive.

A wide range of human activities have the potential to result in harm to health or the environment. HW have properties (e.g. toxicity, persistence, flammability) which increase that potential and require careful management to minimise or avoid.

The risks from HW occur at the point of generation and all along the chain of storage, handling, transport, treatment and disposal. Those exposed to the risks include:

- workers in manufacturing and process plants where the wastes are generated
- workers involved in handling the waste
- members of general public

In addition to the direct human risks, there are risks for the environment, for example from gaseous emissions from uncontrolled dumping, or ground contamination.

By definition, HW has the potential for harm because of their hazardous properties which could cause physical harm, death or illness in humans, or ecological damage. HW is most frequently hazardous to human health or the environment because of their chemical composition. There is a wide variety of chemicals and chemical compounds which might pose a risk. Not only must HW be handled in a way which keeps them away from people, water courses and other sensitive receptors, but some wastes must also be kept away from other wastes, because of their incompatibility and the risks of chemical reactions or explosions.

Humans can get exposed to HW through following routes:

Direct physical harm arising from equipment, collapsed landfills, explosions, fires, waste-related transport accidents and similar incidents, as well as extremes of temperature and wind chill.

Infection: Bacteriological, protozoal pathogens and similar infective agents arising from the biological contamination of wastes and hence their subsequent infective transmission to a host. Transmission routes via



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hand to mouth, and hand to food to mouth, are most likely for waste workers, while contamination of water supply or uptake through the food chain would have a wider effect on the general public.

Chemical contamination: Similar transmission routes may apply to chemical contaminants from waste by affecting susceptible organs or regulatory and control functions within the body. The chemical inducement of cancers is also a possibility.

Chemical alteration: The impact of chemical or bacteriological contaminants on reproductive processes, notably sperm counts, low birth weights and specific birth defects. Perhaps also chemically-induced genetic damage from exposure to certain organic compounds.

Where there are high standards of waste handling, treatment and disposal, risks to health and the environment are low or negligible. However, where standards are not high and modern practices are not employed, the potential health risks are likely to be higher, and the risks of environmental damage considerable.

Typical situations where health risks may be higher are:

- Countries or regions where there is insufficient financial and/or institutional commitment to modern HW management
- Locations where poorly operated treatment or disposal sites have been sited in the past, resulting in residual contamination of land or water courses.
- Countries where there is an absence of institutional or public pressure to raise HW management standards as a matter of social priority.

There is limited direct epidemiological evidence of health effects arising from either municipal or HW management. Extensive research into health effects from chemical wastes was undertaken in the USA during the 1980s and 1990s. These investigations found a 'plausible link' between a chemical pollutant and measurable illness in only a minority of locations, and even then there were a number of confounding factors which made the link difficult to prove. Confounding information from outside influences - such as life style, diet, genetics - can affect the certainty of any apparent causal link. Two other factors which affect the findings are that many of the studies use results based on animal research, rather than humans, and often the toxic effects are calculated on the basis of pure chemicals, not chemicals in waste.

Despite limited evidence to confirm any links, the public often has concerns about the environmental and health risks posed by HW. As has been stated, most studies in the developed world show little clear evidence of elevations in waste-related disease in waste management workers, nearby residents or the general public. The principal demonstrable problem from properly managed HW is that of nuisance, from odours, traffic and noise associated with the waste management operations – and these are similar for all kinds of waste management and industrial facilities. However this does not reassure the general public, who have concerns about a range of potential impacts on their lives. A lack of trust in the authorities responsible for overseeing and enforcing HW management practices often exacerbates the public's concerns. It is important that the public be involved in the deliberations about HW management systems, and that they understand the issues. A public information and education programme should be undertaken as part of the system planning. Such a programme must raise awareness of the risks posed by uncontrolled HW, and the positive public health and environmental benefits of well-managed waste. Even in countries where HW may currently be poorly or improperly managed, public information programmes can be valuable in raising awareness of the need for change.

4. RISK ASSESSMENT AND STANDARDS



The EPA and other regulatory agencies have over the years frequently opted for risk-based standards. The risk assessment process for evaluation of chemical hazards varies according to the proclivities, experiences, focus and/or man dates of the individual risk assessor, researcher or regulatory agency. The process usually consists of the following four steps [Blackman, 2001]:

- Hazard identification
- Dose-response evaluation
- Exposure assessment
- Risk characterisation

Hazard Identification is the process of determining whether exposure to a chemical agent can cause an increase in the incidence of a particular adverse health effect (e.g., cancer, birth defects) and whether the adverse health effect is likely to occur in humans. The process examines the available scientific data for a given chemical (or group of chemicals) and develops a weight of evidence to characterize the link between the negative effects and the chemical agent [EPA (c)]. The toxicological evaluation should also identify any known quantitative indices of toxicity such as the threshold level or No Observable Adverse Effect Level (NOAEL), Lowest Observable Adverse Effect level (LOAEL), carcinogenic risk factors, etc.

Dose-Response evaluation is the process of quantitatively evaluating the toxicity of a given chemical agent as a function of human exposure to that chemical agent. The relationship between the dose of the contaminant administered or received and the incidence of adverse health effects in the exposed population forms the basis for the quantitative dose-response relationship. From these relationships, toxicity values (e.g., reference doses and slope factors) are derived that can be used to estimate the incidence or potential for adverse effects in an exposed population [EPA (c)].

Figure 2 illustrates the NOAEL and LOAEL described earlier. The TD50 and TD 100 points indicate the doses associated with 50 and 100% occurrence of the measured toxic effect.

Figure 3 explains how the hazardous materials from the environment can enter into human body i.e. through inhalation of volatile or particulate matters emitted in the air or ingestion of chemicals leached into soil, groundwater or surface water.

Chemicals in the environment can enter into human body through the food chain (uptake by edible plants and animals) and also become increasingly concentrated in the tissues of animals and human beings higher up in a process called 'bio-magnification', and can do more harm. Chemicals are also 'bio-accumulated' in organisms (plants and animals) to a concentration that exceeds in the surrounding environment (air, soil and water) several times.

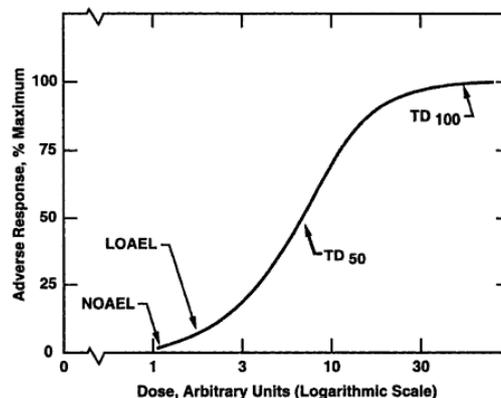


Figure 2. Hypothetical dose response curves [ICAIR].

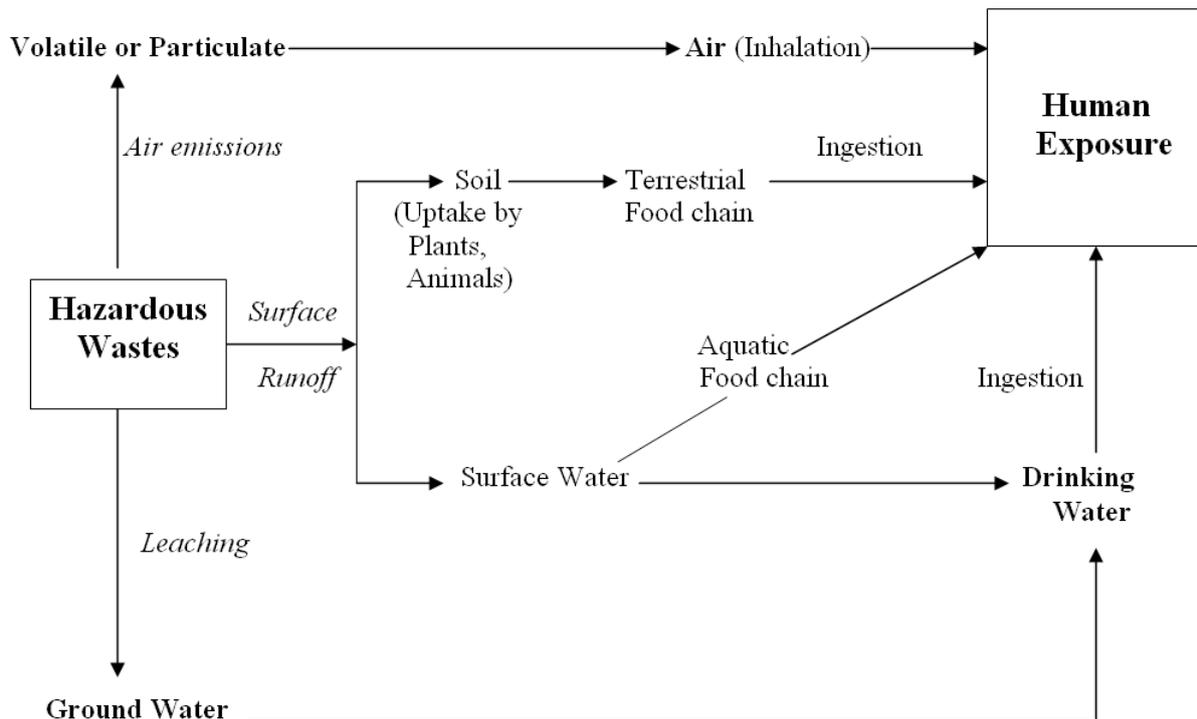


Figure 3. The Pathway to Human Exposure of Hazardous Wastes in the Environment.

E.g. fishes living in water contaminated by dichlorodiphenyltrichloroethane (DDT) can have DDT concentrations 10,00,000 times more than that found in water. Birds and humans eat these fishes and as a result bio-accumulate huge doses of DDT in their bodies. Significant amount of DDT from the soil and water bodies has 'bio-accumulated' in the cereals and pulses and the meat and milk consumed by the human beings. Significant concentrations of DDT ranging from 3 to 26 ppm have been found in the body fat of human population across the world. Human breast milk often contains more toxic materials than the dairy milk. At death, human bodies have been found to contain (bio-accumulate) enough toxic and heavy metals to be classified as HW.

Exposure Assessment is the estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure. Exposure occurs when there are complete pathways between a chemical or physical agent and humans. Exposure assessments may consider past, present, and future exposures using varying assessment techniques. This may include fate and transport models or the results of environmental sampling and analysis. The exposure assessment process includes the following steps: (1) characterize exposure setting, (2) identify exposure pathways, and (3) quantify exposure [EPA (c)].

In Risk Characterization, the information from Hazard Identification, Exposure Evaluation and Dose-Response Assessment are summarized and integrated into quantitative and qualitative expressions of risk. To estimate potential non-carcinogenic effects, comparisons are made between projected intakes of substances and toxicity values; to estimate potential carcinogenic effects, probabilities that an individual will develop cancer over a lifetime of exposure are determined from projected intakes and chemical-specific dose-response information. Major assumptions, scientific judgments, and to the extent possible, estimates of the uncertainties embodied in the assessment are also presented [EPA (c)].

5. MANAGING HAZARDOUS WASTE ON-SITE

There is a need for a structured HW management system which begins as soon as the waste has been



generated and continues through all subsequent stages to final treatment and disposal. In the simplest form, a HW management system comprises three units:

- Storage upon generation
- Collection and transportation
- Final treatment and disposal

Handling and storage are both important factors in all the above management stages, from cradle to grave. Different materials have to be handled in different ways, and may have special storage requirements. For this reason proper identification and labelling of materials is essential, and is likely to represent the difference between a safe HW management system and a dangerous one. Correct handling, storage, packaging and labelling are vital if accidents are to be avoided and the environment is to be protected. The HW management system consists of a series of actions to control and contain the waste. This must be coordinated so that the various persons and groups of persons involved at the different stages are aware of their role and how that role fits within the larger structure. This is particularly true of handling and storage procedures.

A 90-day accumulation period allows the generator to collect enough waste in order to make transportation more cost effective. A generator may accumulate HW on site, provided the following accumulation-related requirements are met [Blackman, 2001]:

- Proper management- The waste must be properly accumulated in containers, tanks, drip pads or containment buildings. Containers must be kept closed and marked with the words "Hazardous Waste". Tanks and containers must be marked with the date on which accumulation began. The generator must ensure and document shipment of the waste off-site within the allowable 90-day period.
- Emergency plan- A written contingency plan and procedures for managing spills or releases must be developed. Generators are required to have a written emergency plan.
- Personnel Training- Facility personnel must be trained in the proper handling of HW. Generators are required to have an established training program in order to ensure that employees handling HW are familiar with proper procedures.

Storage site selection- HW materials must be stored in a safe place. Ideally the storage must take place near the place where the HW is generated. However, storage can be managed on-site or off-site. On site storage - within the premises of the waste generator- requires a storage site not only away from the manufacturing and processing areas, but also away from the areas of employee activities, and in a place not subject to flooding. Off-site storage – outside the premises of the waste generator- may be, for example, at waste collection or transfer stations, pending final treatment and disposal.

While the storage site should ideally be at least 200 metres away from residential areas, this is not always possible. Locating the site within an industrial area helps keeping it far from residential areas and it is more likely to be compatible with the requirement to be surrounded by land use.

Storage site design criteria- Whether it is stored on-site or off, any of the HW storage areas must be designed in such way to minimise the possibility of an explosion or any unplanned sudden or gradual release of HW to air, water or soil. The following design criteria should be observed:

- **Waste compatibility:** different HW should be stored in separate compatible areas;
- **Distances from boundary and traffic:** HW should be stored away from traffic, including both vehicular and foot traffic. Ignitable and reactive wastes should be stored at least 15m from the facility's boundary, if possible - in the case of small sites this may not be possible;
- **Base material:** an impermeable base should be used for the area where containers are located, to



prevent any leaks or spills, or accumulated precipitation, from seeping into the ground;

- **Leak and spill containment:** the storage area must be designed and operated to contain any leaks and spills e.g. with bunds. For outdoor storage facilities, the maximum probable quantity of runoff must also be considered. Regulatory agencies, such as fire departments, may specify certain containment requirements;
- **Climate and environment:** weather conditions can frequently be an important factor in determining storage conditions. Heat, cold, moisture, and wind can adversely affect storage of all chemicals. If waste materials must be stored outside, they should always be covered by a roof or tarpaulin and be kept away from direct sunlight;
- **Ventilation:** adequate ventilation should be provided to prevent build-up of gases. Any area used for storage of chemical wastes or any other hazardous material should be well ventilated;
- **Stack height:** drums should not be stacked more than two high. Drums containing flammable liquid should not be stacked;
- **Eye wash station:** an eye-wash station must be located in each storage area;
- **Drainage system:** floors should be sloped towards retention pits or drains. The drainage system should ensure that any spilled wastes or precipitation do not remain in contact with the waste containers. Alternatively, storage could be on elevated platforms or pallets – this also simplifies inspection. Any spilled or leaked waste, or storm water run-off, should be removed from the sump or collection area as soon as possible to prevent any overflow. (This collected waste must then be correctly handled as HW);
- **Earthing:** when pumping waste or emptying and filling containers, it is necessary to earth the process;
- **Adsorbent material:** should always be present to clean up spills immediately;
- **A separate repackaging room:** any items which are seen to be incorrectly or inadequately packaged can be taken here;
- **Agency requirements:** government agencies, such as the fire department, should be contacted prior to the design and building of a storage structure to incorporate any other specific requirements they may have.

Hazardous waste compatibility- Compatibility refers to the ability of two or more materials to exist in close association with each other without the formation of harmful chemical or physical reactions. The concept of compatibility, when applied to HW, refers to:

- The way chemicals react when in contact with each other
- Chemicals' compatibility with the containers in which they are stored, otherwise there is a risk of container failure resulting in environmental damage or personal injury. For example, acid should not be stored in steel drums, or pressurised materials in weak containers.
- Compatibility with nearby materials and equipment. For example, containers of flammable materials should be stored with proper consideration of proximity to heat, electrical sources and open flames. All flammable containers 20 litre or larger should be earthed.
- Compatibility with the environment itself. Storing many waste materials outside may be practical, but storing drums of highly flammable material in dark drums in open sunlight can be extremely dangerous.

Incompatibility between two chemical substances can result in one of a number of reactions, for example:



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Acid + cyanide solution = cyanide gas

Bleach + ammonia = chlorine gas

Water + lithium aluminium hydride = a difficult fire to extinguish

Water + strong acid = dangerous evolution of heat and gas

Organic material + strong oxidiser = fire

Duration of hazardous waste storage- HW should be stored at any location as briefly as possible, to avoid leakage or spill, or decay of containment. Legally permitted temporary storage durations are different from country to country and are in part dependent on the availability of treatment and disposal facilities. For example, while many Western European countries limit temporary storage to 28 or 90 days, in Norway the generator may store the waste for up to one year, regardless of size, providing the regulations on storage design and management are met.

By comparison, in the USA federal regulations group waste generators according to the amount of waste they generate. Large quantity generators may accumulate HW up to 90 days in standard storage areas. Medium quantity generators may accumulate HW up to 180 days in standard storage areas, or store for up to 270 days if they have to transport waste over 300km; they are prohibited from exceeding 6000kg of HW on site at any one time. There is no duration limit for small quantity generators; when the total quantity of waste exceeds certain specified limits, the generator has three days to comply with small quantity generator requirements.

While storage should ideally take place in a short term, it is possible to store long term, providing that proper measures are followed.

Long term storage- Where waste is to be stored for the long term, it is important that proper controls should be placed on storage facilities. Where there is a chance that storage may be indefinite, these should be similar to the controls on final disposal facilities. This will help deter the mis-use of storage to disguise uncontrolled disposal practices.

An example of inappropriate long term storage of waste is the stockpiling of obsolete pesticides in some countries. Because the conditions were not properly controlled, drums have corroded or buckled, and storage areas have flooded, resulting in extensive local contamination and risks to human health.

In some parts of Europe, such as Portugal, and in the Far East, HW may be stored indefinitely. This is a practical solution to the severe shortage of HW facilities. As treatment and disposal facilities become available in developing economies, there is an opportunity to tighten regulations on storage duration. However, in the meantime the stored waste are kept containerised and the facilities are licensed and controlled.

Types of storage- The type of storage must be matched to the waste material, in relation to its physical form as well as its characteristics. The later treatment and disposal options may also influence the storage decisions. Small amounts of similar or diverse wastes may be containerised. Large volumes of liquid wastes may be stored in tanks, while large volumes of solid materials may be stored in bunkers, silos or skips.

Packaging materials- A wide variety of packaging materials are available for handling and storage of HW, most of which have two basic characteristics. Firstly, the packaging material must be inert and not react with the HW. Secondly the material must be able to absorb impact in case the container is bumped or dropped. The choice of material used will depend on various factors, including:

- the HW type (for example, plastic containers should not be used to store solvent wastes)
- the physical form of the HW (e.g. paper is no use for liquids)
- the type of container (e.g. drums need to be of rigid material).

The ease with which packaged waste can be handled is also an important consideration.



Types of containers- Hazardous materials being either moved or stored need to be stored into containers in some way. The kind of container reflects the type of waste to be stored, and the handling method in use. For example, some containers are more suitable for filling by pumping, and some more suited to filling by shovelling.

There are many types of packages available for different types of waste, including:

- **Bags:** flexible packs made of paper, plastic film, textiles, woven or other materials
- **Boxes:** packaging with complete rectangular or polygonal faces, made of metal, wood, plywood, reconstituted wood, fibreboard, plastic or other suitable material
- **Drums:** flat-ended or convex-ended cylindrical containers made of metal, fibreboard, plastic, plywood or other suitable materials.
- **Jerrycans:** metal or plastic containers of rectangular or polygonal cross-section.

Some containers are multi-material e.g. a plastic bag inside a metal drum, or multi-layer e.g. plastic coated paper. Some storage containers may combine one or more inner packs secured inside an outer packaging.

Suggested containers:

- Waste oils and solvents may be best suited to storage in 200 litre steel bung drums or tanks.
- Solid or semi-solid organic wastes may be best suited to 200 litre steel clamp lid drums.
- Inorganic liquid wastes may be best in plastic cans or polyethylene tanks of 30, 45 or 200 litre capacity.
- Inorganic solids and sludge might be stored in 200 litre steel or plastic clamp lid drums.

Container selection criteria- The selection of suitable materials and container types for HW should be made based on the requirements of each storage and handling application. As has been stated, suitable containers should be constructed of inert material which will not react with the HW. Properly selected, designed and constructed containers are impervious by their contents. In addition, the container material must not form other dangerous substances when come in contact with the contents. In addition to being able to absorb impact, in case they are bumped or dropped, storage containers must be in good condition. This includes being free of leaks, structural defects or rust. The outside must be clean without holes, bulges or cracks. The containers should remain closed at all times, except for cases when waste material is being added or removed. The container must be designed so that its contents will not released when subjected to normal handling.

Containers must be well-made and robust. For example, if a vessel has a re-sealable closure or plug, that closure must be able to bear repeated use without sustaining damage, which could allow the contents to escape. Packaging materials or containers may often be reused. In this way we save money and reduce wastage while is acceptable providing the container was not contaminated during its previous use. Empty raw material containers may be suitable for use as HW storage containers, depending on the compatibility of the waste with the container material and also the compatibility of any residues of the raw material which may be present. In the case that a container which held incompatible material needed to be re-used, it must first be triple-washed.

The amount of packing material or size of container needed to be determined by the volume of waste. Containers should not be over-filled: for example, drums should never be filled more than 90%.

- **Drums and cans-** In many cases, reconditioned drums can be safely used to store wastes. In industrialising countries, the re-use of raw materials drums is common practice. Drums are valuable for vertical storage space as they can be stacked, but on the other hand they may present some



handling problems because of their weight. New drums may be expensive but re-use drums, or purchasing reconditioned drums (which are usually available for approximately half the cost of new drums) reduces costs. If considering the use of reconditioned drums, it is important to inspect their quality and condition, and to ensure that any previous contents are completely removed, particularly if those contents may be incompatible with the waste. Drums which have been used for the chemicals from which the HW result can be used. Cans are available in a range of sizes (from 10-60 litres) and are used for acid and alkaline liquid waste, liquid chemicals (for example acids and bases, fixer and developer solutions).

- Tanks- Tanks are ideal for bulk storage. They are also useful for accumulating waste that can be handled by bulk materials handling systems such as pipelines, or belt conveyors. Tanks offer more rigid and integral containment than containers and are easier to inspect for leaks and spills.

Marking and labelling- An important aspect of the storage of HW is its correct marking and labelling. Without this, it will not be possible to ensure proper handling (e.g. to make sure containers are stored the right way up) and compatible storage, nor to re-direct wastes to appropriate treatment.

Regulations and conventions governing the marking and labelling of HW differ from country to country, but there are some general rules and requirements. Marking differs from labelling in that it describes the physical attributes of a marker (or label) affixed to a container whereas labelling refers to the information which must be displayed on the marker. This information is largely to assist in the transport of wastes and to comply with regulations on transporting of waste within countries and internationally.

For on-site storage, the main requirement is for clear information to be displayed to enable appropriate handling decisions to be taken. The minimum information needed for on-site storage of HW is:

- Waste type
- Physical state of the waste at a given temperature
- Waste composition
- Necessary information on health protection
- Necessary information for fire protection

Markings must be durable, and written in English and/or in the native language. They must be unobscured and placed away from any other markings. They should be in a colour different from and contrasting to the background colour of the container, to ensure that they stand out. When re-using old containers, all old markings should be removed.

All containers and tanks must be clearly labelled with the waste type and hazard posed. Labels should be made of good quality, durable materials which will not be affected by weather. They should not be easily removable. The labels should be well located e.g. not placed on the top or bottom which might become hidden if stacked in storage. They must be legible and recognisable in day time and at night. The label should include information on any handling precautions required and any prohibitions e.g. where other containers must not be stacked on top.

Labels should be at least 100mm square. There are two main types of labels, those which denote a hazard and those which give handling instructions.

- Hazard labels are diamond shaped, and are required in many countries for most dangerous goods, except magnetised materials.
- Handling labels may be in various rectangular shapes and are required either alone or in addition of hazard labels for some dangerous goods.



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Handling and storage hazards for personnel- For personnel there are a number of hazards associated with waste handling. These include physical hazards such as accidental injury from equipment, or from containers falling onto them, as well as explosions and fires, from improperly stored wastes. Respiratory illness and skin disorders can result from exposure to biological hazards while chemical hazards posed include various kinds of skin, eye and respiratory problems. Systemic effects, resulting from the take-up of chemicals by the body through inhalation, ingestion or through the skin, can range from nausea and headaches to cancers. Correct handling and storage of HW is therefore not simply necessary to demonstrate compliance with regulations, or to facilitate subsequent treatment and disposal, but also to protect health and the environment. Different manual and mechanical handling systems - such as mechanical grab loaders, pumping equipment - require different skills, and personnel should be properly trained in the appropriate system.

6. HAZARDOUS WASTE TRANSPORTATION SAFETY

Transportation incidents are frequently involved in major threats to the environment and public-safety. During previous years small locally base refuse haulers provided immediate and cheap removal of HW accumulations on a “no question asked” basis. The most marginal of trucking operations could survive by removing unwanted waste and disposing of it with abandon. As regulatory agencies gained recognition and experience, most of the marginal transporters were eliminated and transportation became a vital link in the cradle-to-grave management strategy. Although illegal transportation activities have continued to require the attention of law enforcement agencies, much of the regulatory focus has shifted to accident prevention, emergency response activity, surveillance of import-export activity and tracking of wastes from source to ultimate disposition.

6.1. Hazardous waste shipment

All practitioners who may become involved in shipment of HW should follow a certain procedure for preparation of HW shipments (see figure 4) and certify that [Blackman, 2001]:

- The shipment has been accurately described and is in proper condition for transport
- The generator has a waste minimization program in place at its facility to reduce the volume and toxicity of HW to the degree economically practicable as determined by the generator.
- The treatment, storage or disposal method chosen by the generator is the most practicable method currently available that minimizes the risk to human health and the environment.

A 1981 report prepared for the EPA estimated that 96% of the 264 million tons of HW generated each year in USA were disposed of at the site where they were generated and that most of the HW shipped off-site was transported by truck. The highway transport mode is regarded as the most versatile. Tank trucks can access most industrial sites while rail shipping requires expensive sidings and is suitable only for very large quantity shipments.

Accident and transportation release statistics provide insight regarding the relative hazards posed by the highway and rail modes of hazardous materials transportation. These data indicate that highway transport experienced 12 times the number of incidents involving hazardous materials, 4 times the number of fatalities and 2 times the number of injuries as occurred in rail transport. However rail accidents released approximately 50% greater quantities than did highway accidents involving hazardous materials [Blackman, 1985].

The “hazmat” employee should have special training in order to perform with safety hazardous material shipment. The required training consists of three categories [Blackman, 2001]:

- *General awareness/ familiarisation training-* the hazards associated with hazardous materials



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transportation, the hazards classes and hazard communication requirements.

- *Function-specific training* the packaging, labelling, marking and placarding of hazardous materials shipment.

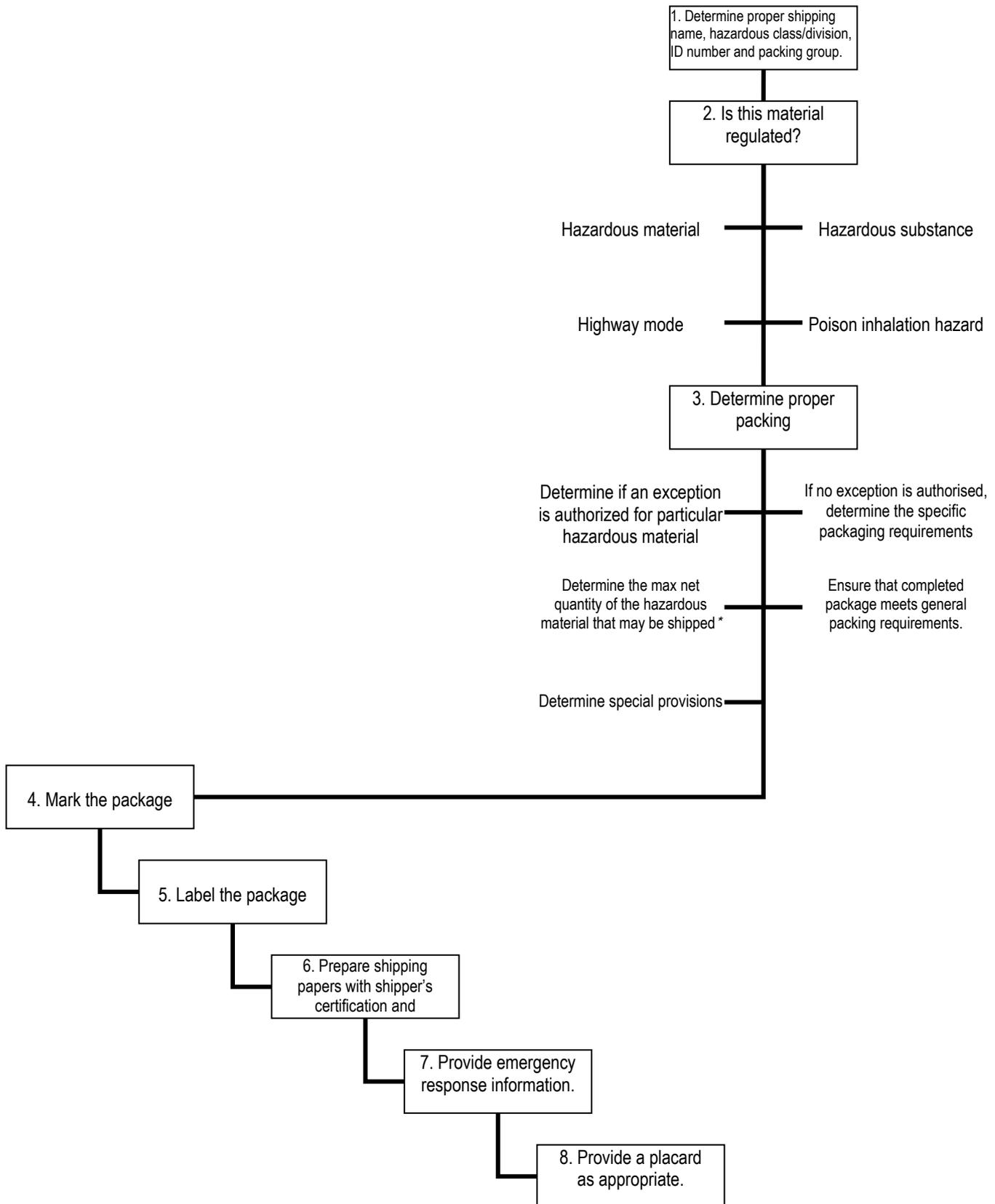


Figure 4. Eight step procedure for preparation of Hazardous waste shipments (*: in one package by passenger-carrying and/or cargo-only aircraft as appropriate) [Blackman, 2001].



- *Safety training*- the emergency response, personnel protective clothing and equipment and methods and procedures for avoiding accidents and exposure.

The standards also include driver training requirements and specialised training for drivers of vehicles transporting explosives, radioactive materials or cryogenic gases. The ‘hazmat’ employee must repeat the training at 2-year intervals and drivers must be trained annually.

6.2. Exports and imports of hazardous waste

About 75% of the generated HW in the EU and Norway is exported for recovery and about 20% for disposal. Portugal, Spain, Luxembourg and the Netherlands export as well a large part of their generated waste for disposal. Figure 5 shows the kind of treatment that the exported HW from the EU has received.

International movement of HW is a matter of growing interest, complexity and concern to responsible officials. If transporting waste to the Organisation for Economic Cooperation and Development (OECD) member countries, there are certain provisions to which the shipper or transported must carefully adhere. When international export of HW is performed several elements must be prior considered:

- Overall stringent environmental laws in most industrialised countries.
- Tightening of specific laws, regulations and policies concerning disposal of certain types of waste.
- Rising costs of HW disposal in the home country where waste is generated.
- Diminishing domestic capacity for disposal of certain types of waste.
- Potential liability for any damages caused by waste disposed of domestically.
- Market opportunities elsewhere for materials which can be recovered, reclaimed or recycled from waste otherwise destined for “final” disposal.

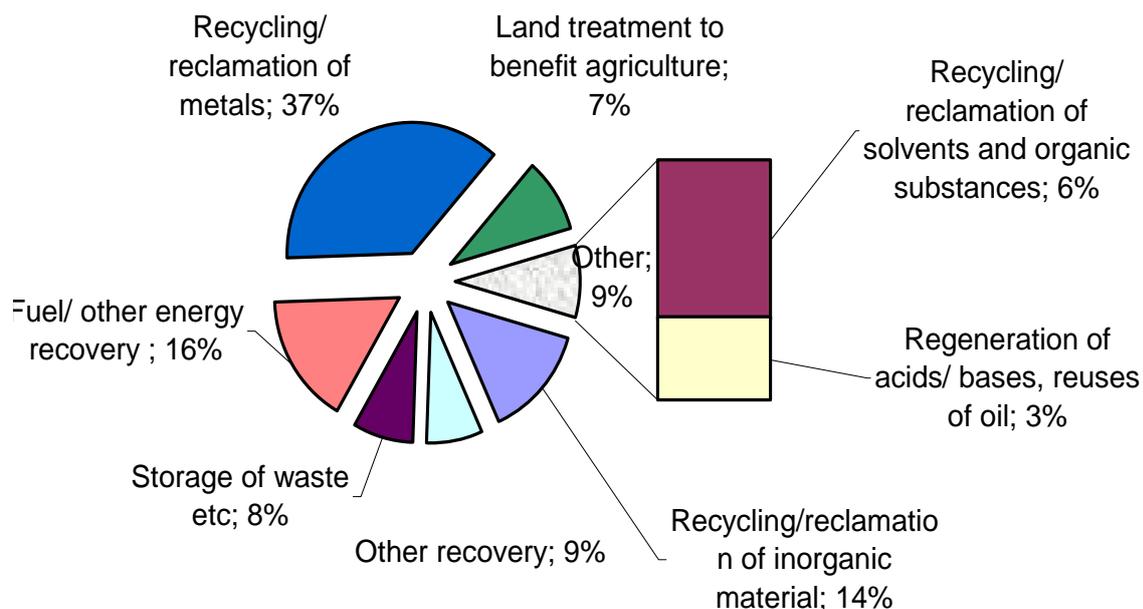


Figure 5. Treatment of hazardous waste according to EU Framework Directive [Adeleke, 2002].



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- General economic growth which may result in more total generation of waste.
- Economies of scales associated with treatment, storage and disposal facilities (TSDFs).
- Existence of TSDFs which may serve several countries.
- Existence of an appropriate TSDF in a foreign country which is closer than a similar facility in the home country.
- Lack of environmental sound TSDFs in some waste-producing countries.

6.2.1. Transfrontier shipments of hazardous waste

The Organisation for Economic Co-operation and Development (OECD) 'council decision' reached in 1992 by the 29 member nations identifies an extensive array of wastes that are subject to a graduated system of controls when waste destined for recovery are moved across the borders of member nations. The agreement is intended to control the trade between recyclable materials and minimise the possibility of abandonment or dumping of HW. Transborder movement among members for disposal purpose is not permitted. The key word in the title and in implementation is recovery. The system creates [Blackman, 2001]:

- A green- list which imposes no additional controls beyond normal international commercial shipments.
- An amber-list of waste that either (1) move on a shipment basis requiring prior written notification and consent from importing and transit countries or (2) move to a facility that is pre-approved by the importing country to accept that waste type with prior written notification only (in both cases the waste must be accompanied by a tracking document under a legally binding contract, chain of contracts or equivalent arrangements within a corporate entity).
- A red-list wherein the waste are handled in the same manner as amber-list waste except that prior written consent from importing and transit countries is always required and no facilities are pre-approved to accept the waste.

6.2.2. The Basel Convention on hazardous wastes

In the late 1980s, a tightening of environmental regulations imposed in industrialised countries led to a dramatic rise in the cost of HW disposal. Searching for cheaper ways to get rid of waste, 'toxic traders' began shipping HW to developing countries and to Eastern Europe. When this activity was revealed, international outrage led to drafting and adoption of the Basel Convention [Bergman, 2010].

The Basel Convention on the Control of transboundary Movements of HW and their disposal is the most important international agreement related to HW. The Basel Convention on the Control of Transboundary Movements of HW and their disposal was signed initially by 33 countries in 1989 and by more than 90 countries by 1996*. The basic objectives of the Basel Convention are for the control and reduction of transboundary movements of hazardous and other waste subject to the Convention, prevention and minimization of their generation, environmentally sound management of such wastes and for active promotion of the transfer and use of cleaner technologies. Parties to the Basel Convention may not trade waste covered by the convention with 'non-parties' in the absence of a bilateral or multilateral agreement to govern

* The US is not presently signator of the Basel Convention; however US importers and exporters are subject to the conditions of bilateral agreements with four countries that are parties to the Basel Convention. Bilateral agreements covering import and export of hazardous waste have been negotiated with Mexico and Canada. The US has bilateral agreements for import of HW with Malaysia and Costa Rica.



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transboundary movements.

Additionally, all parties in the Convention are obliged to regulate and minimize the import of HW or other wastes for disposal or re-cycling and also to prohibit export of waste to parties, which have prohibited the import of such waste. Parties are also required to minimize generation of HW in the country taking into account social, technological and economic aspects. Further, HW generated in those countries is also required to be managed in an environmentally sound manner. DCs, as parties, can prevent the import of HW or other waste if they have reason to believe that the waste in question will not be managed in an environmentally sound manner.

In its Preamble, the Convention recognises the risk of damage to human health and the environment that is posed by HW and other waste and by the transboundary movement of such waste. To accomplish its goal the Convention provides for three key measures with binding obligations on parties, namely:

- strict control of transboundary movement of HW;
- environmentally sound management of HW; and
- enforcement and implementation of provisions of the convention at international and international levels.

In the current and coming phase the Convention aims to encourage [Bergman, 2010]:

- active use of cleaner technologies and production methods;
- reduction in the movement of HW and other waste;
- the prevention and monitoring of illegal traffic;
- improvement of institutional and technical capabilities; and
- further development of regional and sub regional centres for training and technology transfer.

Transboundary waste movement to neighbouring countries has been common. In all cases, properly enforced water pollution and waste disposal legislation, backed by good technical and service infrastructures, has enabled countries to make good progress. The evolutionary nature of HW control is shown schematically by the example in Figure 6 which illustrates how a number of initial measures serve as a base for additional initiatives.

7. HAZARDOUS WASTE TREATMENT

7.1. Options and priorities

The aesthetic effects of HW mismanagement during the mid 1900s are well understood by most citizens. The rise of the NIMBY syndrome exemplifies the fear and revulsion of the public toward hazardous materials in general and HW in particular. The aesthetic concerns quickly transition to economic issues as property values are affected, jobs are created or eliminated and public administrators come under increasing pressures to craft solutions that solve all problems and resolve all issues. Facility siting became a major preoccupation among governments, the regulated industries and facilities and the public. By 1980s public opposition to HW facilities had become so pervasive and intense that even sites with excellent operating records faced closure simply because they were "there". Environmental equity issues usually arising from actual or proposed location of hazardous materials/waste facilities in poor or minority neighbourhoods and even dumping to countries of the developing world, came to the forefront of the urban agenda in the 1990s. By late 1990s the equity issues had become focused in an identified EPA environmental justice program.

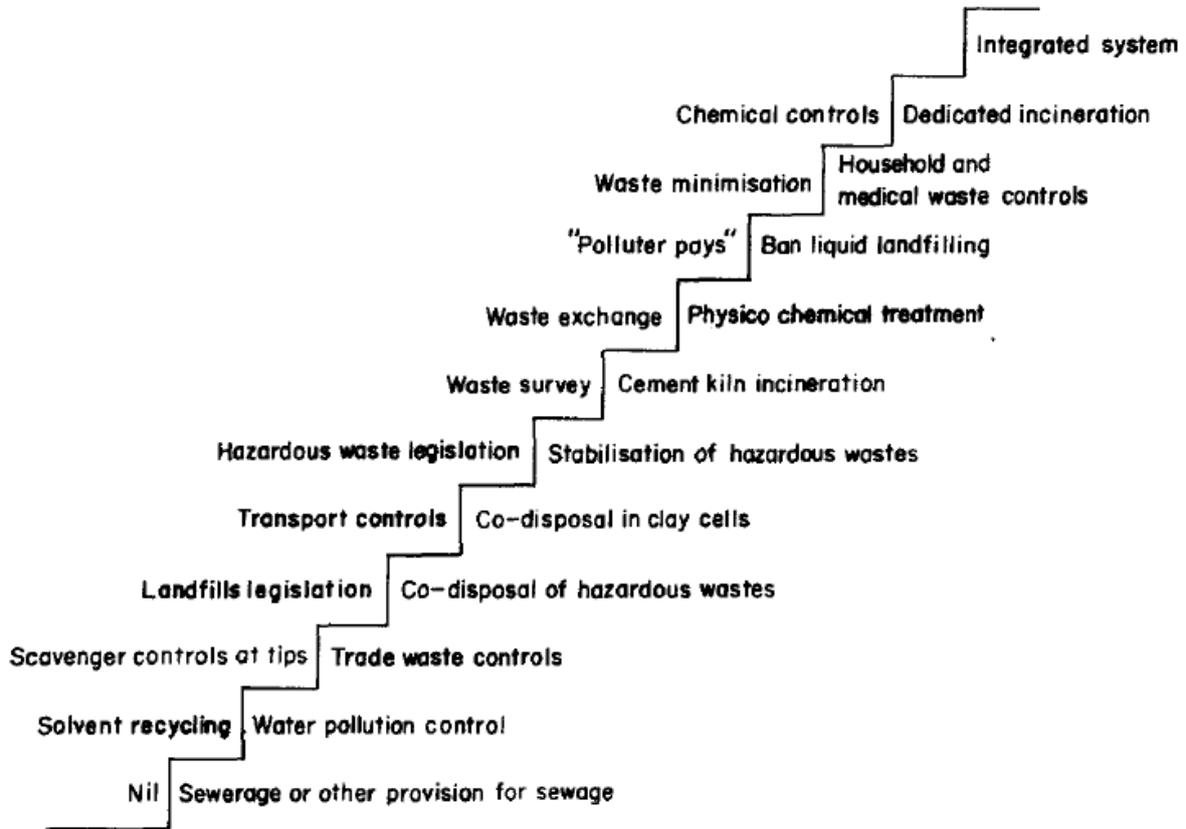


Figure 6. National steps showing the evolution of a hazardous waste management system (the sequence of steps may vary from country to country) [Wilson et al., 1990].

Nowadays HW treatment is a rapidly developing industry full of experimentation and innovation. This innovation is being driven by the need for effective and economical process for reclaiming, treating or destroying waste rather than landfilling them without treatment. A hierarchy of hazardous and general waste management is presented in Table 5.

Table 5. Hazardous waste management options and priorities.

Source reduction (process modification)	BEST ↑ WORST
Separation and volume reduction	
Exchange/ sale as raw materials	
Energy recovery	
Treatment	
Secure ultimate disposal	

HW management is a new concept for most of the DCs. The lack of technical and financial resources and the regulatory control for the management of HW in the past had led to the unscientific disposal of HW in India, which posed serious risks to human, animal and plant life.



7.2. Treatment methods

The main methods of treating and safe disposal of HW can be generally classified into [Adeleke, 2010]:

- Physical and chemical methods (e.g. stripping, carbon adsorption, oxidation, SCF/ SCWO, membrane process, etc.)
- Biological methods
- Incineration and pyrolysis
- Solidification and stabilization
- Landfilling

Table 6 presents the main HW treatment, recovery and disposal processes whereas Figure 7 aligns types or categories of industrial waste with the treatment process and ultimate disposal usually applied.

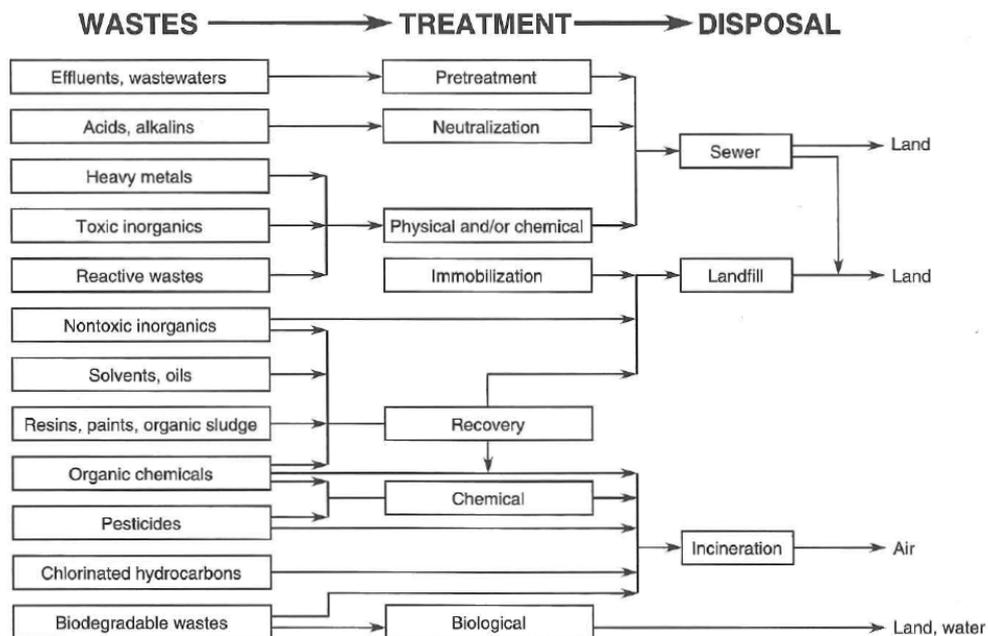


Figure 7. Treatment and disposal alternatives for industrial waste [Blackman, 2001].

Table 6. Hazardous waste treatment, recovery and disposal processes [Blackman, 2001].

TREATMENT PROCESSES				
Physical	Chemical	Biological	Thermal	Ultimate disposal
Gas cleaning	Absorption	Aerobic systems	Incineration	Deep-well disposal
Liquids- solids separation	Chemical oxidation	Anaerobic systems	Pyrolysis	Dilution and dispersal
Removal of specific	Chemical	Activated	Vitrification	Ocean dumping



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TREATMENT PROCESSES				
Physical	Chemical	Biological	Thermal	Ultimate disposal
components	precipitation	sludge		
	Chemical reduction	Spay irrigation		Sanitary landfill
	Wed oxidation	Tricking filters		Land burial
	Ion exchange	Waste stabilisation ponds		
	Neutralisation	Rotating bio contactors		
	Chemical fixation and solidification			
	Dehalogenation			

7.2.1. Hazardous waste minimization, reuse and recycling

Management should wherever possible devise and incorporate good operating practices to improve production scheduling and planning. Improved production techniques may include maximising batch size, dedicating equipment to a single product or alternative batch sequencing to reduce cleaning frequency. Production runs a given formulation should be scheduled together to reduce the need for equipment cleaning between batches. Careful examination of workload distribution may reveal opportunities for waste reduction. Dense loading may result in localised instability of the process solution. In other situations maximising batch size may minimise waste generation. Optimising production schedules can greatly reduce waste in a production facility. Such options may offer easy implementation and immediate evidence of results. HW reuse, recycling, and reclamation can avoid environmental hazards, protect scarce natural resources, provide economic benefits, and reduce the nation's reliance on raw materials and energy [EPA, 2008].

- **Environmental Benefits-** Recycling HW fulfils two of RCRA's goals by reducing the consumption of raw materials and by reducing the volume of waste materials that must be treated and disposed of. Recycling HW can mean less air, water, and soil pollution associated with the extraction, refining, and processing of raw materials. Recycling also can reduce emissions of greenhouse gases (GHGs). When HW is recycled, less energy is needed to extract, transport, and process raw materials and to manufacture products. On the other hand, when energy demand decreases, fewer fossil fuels are burned and less carbon dioxide is emitted into the atmosphere. Emissions of other air pollutants can be reduced, too, as recycling HW can decrease releases of air toxics from waste incineration.
- **Economic Benefits-** HW recycling can be good both for the environment and the bottom line. Recycling HW can increase production efficiency and reduce costs associated with purchasing raw



materials and waste management. By recycling hazardous materials, a business may be able to eliminate the generation of HW and avoid RCRA regulatory requirements altogether. A business may also benefit from the positive or "green" image associated with HW recycling efforts. For example a company who values strong corporate stewardship can increase goodwill with shareholders and consumers and further distinguish itself from its competitors.

Recycling of HW management refers to the effective use or reuse of waste as a substitute for commercial product or use of a waste as an ingredient or feedstock in an industrial process. It also refers to reclaiming useful constituent fractions within a waste material or removing contaminants from a waste to allow it to be reused.

Many industrial HW can be recycled safely and effectively. HW is recycled if it is used, reused, or reclaimed. HW regulation makes an important distinction between materials that are used or reused without reclamation and those that must be reclaimed before reuse. A material is reclaimed if it is processed to recover a usable product, or if it is regenerated. Common HW reclamation activities involve recovery of spent solvents (e.g., recovery of acetone) or metals (e.g., recovery of lead).

One of the most basic and frequent applications of HW recycling is the distillation of spent solvents (see Figure 8). Large numbers of companies are engaged in the solvent reclamation business and much of the solvent in use has been reclaimed. Reclamation is processing a material to recover a useable product, such as recovering mercury from broken thermometers, or regenerating a material, such as cleaning used solvents to make them pure again. Reclamation activities are regulated differently depending on the type of HW to be recycled. Certain reclaimed materials enjoy "relief" from all HW regulations. Other materials, however, are subject to full regulation when reclaimed. EPA made this distinction based on the level of threat posed by common industry practices associated with reclaiming different types of materials (see example below) [EPA, 2000].



Figure 8. Distillation columns.

A printed wiring board (PWB) operation uses ammoniacal etchants to etch patterns on PWBs. The spent etchants is sent back to the chemical supplier, where the copper is extracted with an organic solvent to create a copper rich organic layer and copper-lean aqueous solution. The aqueous phase is regenerated by the addition of ammonia and other additives to create fresh etchants. The organic layer is treated with sulphuric acid to remove the copper from the organic solvent. Regenerated solvent is fed back into process and the copper in the aqueous stream is recovered as copper sulphate pentahydrate via crystallization or as copper metal via electrowinning. Copper sulphate recovered by this process can be used to manufacture other copper-based chemicals or used directly in applications such as wood preservatives or algicide. A simplified



schematic is shown in figure 9.

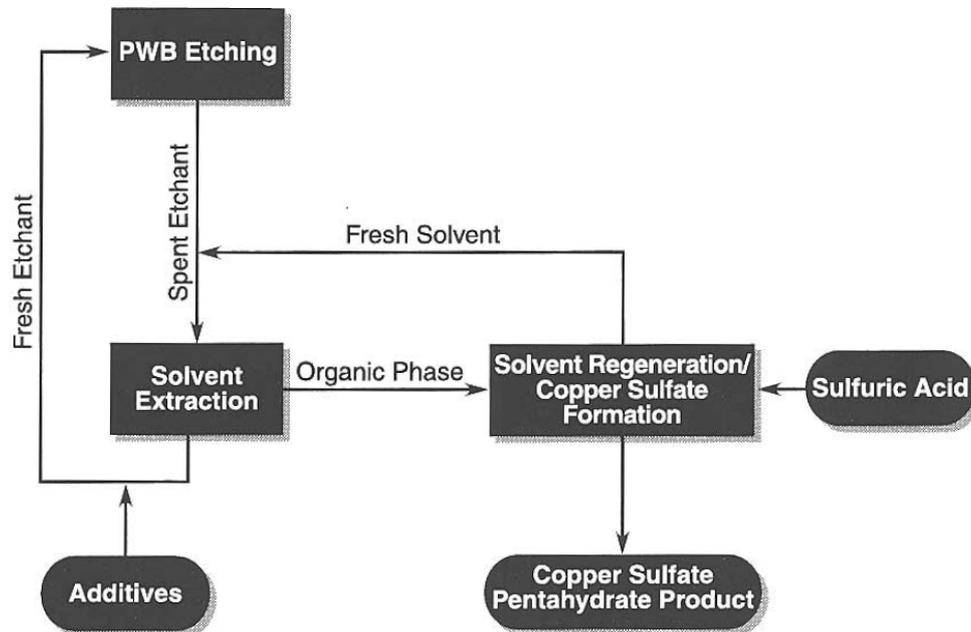


Figure 9. Alkaline ammonia etchant cycle [Milliman et al., 1999].

The final type of HW recycling activity uses directly the waste (without reclamation) as an ingredient in an industrial process to make a product or as a substitute for a product. During this process, a facility uses a HW directly in place of a product, if the waste is similar enough to function in a similar manner. Since direct reuse of the material presents a low risk to human health and the environment, EPA does not regulate these activities, unless the waste will be burned or placed on the land. EPA will evaluate the legitimacy of a recycling practice by ensuring that it is not an attempt to avoid proper treatment or disposal and that the material is recycled in a timely manner [EPA, 2000].

7.2.2. Physical and chemical methods

The term physico-chemical treatment generally covers a range of cool processing techniques which do not include any biological processes. Like other treatment processes, physico-chemical treatment aims to reduce the hazardous potential of waste, but physical and chemical processes may also offer opportunities to re-use or recycle parts of waste, reducing the volume needing disposal. Chemical processes rely on chemical reactions to transform HW into less hazardous substances, using the chemical properties of the waste itself to effect the transformation.

Some physical treatment processes may be undertaken on-site by the waste generator. The advantages of on-site treatment include the reduction of waste volumes needing transport to off-site treatment, and the associated savings in costs. On-site treatment is likely to include relatively low cost, high volume treatment processes such as:

- Sedimentation of aqueous wastes
- Neutralisation of acids-alkalis
- Concentration of heavy metals from any metal finishing by precipitation



Although some physical treatment processes may be undertaken by the waste generator on-site, particularly for large volume waste streams such as aqueous wastes, the inter-related functions of physico-chemical treatment are typically undertaken at a dedicated facility. Such facilities need to provide the different areas served by an effective safety management system and trained personnel to ensure proper operation.

All physico-chemical treatment processes generate residues. These residues are often themselves HW, and may be more concentrated than the original waste although lower in total volume. If the residue stream is pure, it may be suitable for recycling e.g. oils from flotation, metals if segregated. Alternatively they may require further treatment, such as solidification e.g. mixed metal sludges. Others may require incineration e.g. distillation residues. Ultimately there will usually be some residue remaining for landfill disposal e.g. solidified wastes, incineration residues.

7.2.2.1. Physical methods

There is a large number of different physical treatment processes, most of which are simple and low-cost. Many physical processes rely on gravity, but this basic principle may be adapted in different ways within different processes in an attempt to optimise its effects. Other physical treatment processes use the different properties of materials e.g. boiling points, particle sizes.

The choice of process is dictated by the form of waste (*e.g.* dry powder, liquid) as well as its characteristics aiming utterly to separate harmless or non-hazardous components from hazardous components. The later are destroyed in secure facilities or they are disposed.

Separation is simple sieving and screening of waste which can be undertaken with dry materials of different particle size.

Distillation can be used to separate liquids, relying on the different boiling points of the different liquids. This is a standard method for solvent recovery. The use of a washing medium may also be used, for example to extract contaminants from soils, or to wash soluble components from solid wastes, such as aggregates or gravel.

Adsorption is used to remove hazardous components from liquid or gaseous HW, and is commonly used to remove trace organic constituents from wastewater. Granular activated carbon is the most commonly used adsorbent material, but may be expensive. Adsorption is especially useful in the final stages of waste treatment, and is often used in combination with other treatment methods.

Sedimentation uses gravitational forces to settle the denser components in an aqueous liquid. For HW, there is a wide possible range of waste types that may be treated in this way. Simple sedimentation tanks are static cylinders with a conical base from which collection and thickening of sludge is facilitated. Depending on the gradient of the base cone, mechanical or manual stirring may be necessary to collect the sludges. Sludges once collected are either pumped or moved (*e.g.* by mechanical buckets) for further screening, or to drying or dewatering facilities while the separated liquid may need further treatment before disposal.

Flotation relies on the natural floating effects of particles which are less dense than water. The efficiency of flotation can be improved by blowing air through liquid. The bubbles attach to the light particles and gather together to make foam on the surface. The size of the air bubbles can be varied according to the waste type, with small bubbles being more efficient but requiring more precise equipment which in turn requires more maintenance. If the bubbles of air are too big they have the opposite effect from that desired *i.e.* they encourage mixing rather than separation of the different materials. Flotation is the standard way of separating oil and water mixtures.



Drying and evaporation: After sedimentation, sludges still contain high percentages of water and may need to be further dried before disposal, depending on the regulations concerning the disposal route *e.g.* land spreading. There are a number of ways for the sludge to be dried as described below:

Sludge drying beds: This simple, low cost method is only suitable in certain climates, for some wastes and for small quantities. Sludges are poured onto sand from where the water will either evaporate off or will percolate into the sand. It is important to be sure that this process does not result in undesirable matter in the sludge being returned to the environment.

Centrifugal separation: This method uses centrifugal force to accelerate the separation of sludge into particles and liquid, resulting in clear liquid and a sludge cake. Sludges containing sand cannot be treated in this way, because of the abrasive nature of the sand. Sludges containing long fibres or bulky items are also not suitable. Because the operation of the centrifuge requires a power supply, this may not always be a suitable option.

Filtering and pressing: Filtering of wastes is probably the most common physical treatment method. It is suitable for a variety of different wastes and there are a wide range of different filters and filter presses which can be used. These include membranes, bar screens, filter presses and belt filters. Filter processes are often an integral part of the primary production process, to reduce the quantity of waste generated. Membranes are used for simple filtration, with the size of the mesh screen dictating the efficiency of the process. Membranes are also used for reverse osmosis, for example for oily waste and leachates.

7.2.2.2. Chemical methods

Chemical treatment processes may be used to alter chemical properties of waste in order to facilitate or enable further treatment; to render the waste non-toxic/non hazardous for disposal; or to solidify or stabilize the waste for ease of handling or reduced leachability or to render them non-degradable. The general categories of chemical treatment include acid/base neutralisation, chemical precipitation, oxidation/reduction (redox), solidification/stabilisation, electrolysis, hydrolysis, chemical extraction and leaching.

- **Neutralisation** is a widely used chemical process in which pH of an acidic, corrosive or caustic wastewater or gas is adjusted to a more neutral range. This process may be employed as a pre-treatment step or final treatment process.
- **Solidification and stabilization.** Stabilisation and solidification of liquid and semi-solid waste are process used to immobilise the hazardous constituents and provide physical structure to waste in order that it can be easily handled and land-disposed with minimised hazard to the land and groundwater. The process may involve some chemical reactions but primarily used to dewater and/or achieve physical encapsulation of the constituents.
- **Oxidation/reduction (redox).** The chemical process of oxidation and reduction can be used to render HW less hazardous or harmless. An oxidation reaction increases the valence of an ion with a loss of electrons. A reducing reaction decreases the valence with a gain of electrons. Reactions that involve both oxidation and reduction are known as redox reactions.

Neutralisation: Neutralisation is a common industrial treatment process for a wide variety of acidic and alkaline wastes. Neutralisation is most often used to treat liquid wastes, but sludges and gases are also treated. When they are outside the pH range 4.3 – 8.3, acid wastes are neutralised by alkalis, and vice versa. Self-neutralisation is often used, where waste acid and waste alkali neutralise each other. Otherwise, lime or sodium hydroxide are the most widely used neutralising agents for acids and sulphuric and hydrochloric acid are the most commonly used neutralising agents for alkalis. Each neutralisation process must be previously tested in laboratory to avoid reactions which may be too slow, too rapid or have undesired gas emissions.



Precipitation: Chemical precipitation causes soluble substances to become less soluble or insoluble. The treatment is effective in treating wastewater containing toxic metals such as arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel and zinc. These metal-containing wastewaters arise for example in the metal-plating and finishing industry and in mining.

Precipitation using calcium hydroxide is the most widely used method, but carbon, sulphide and sodium borohydride are also used. Precipitation is often used in combination with other treatment processes. For example, after reducing CrVI to Cr III, the CrIII is often precipitated. Similarly, after neutralisation, metals may be precipitated. Precipitation may itself be followed by sedimentation or solidification.

Reduction and oxidation: This process is used to reduce or destroy the toxicity of waste by changing its state of oxidation. Solutions containing hexavalent chromium, cyanides, sulphides and many organic wastes such as pesticides and phenols are treated by reduction or oxidation. The origins of many waste treated in this way are from electroplating, metals manufacturing and ore extraction.

While many chemicals are theoretically easy to be used for reduction and oxidation, in practice they are less easy. There are also many risks with certain chemicals. The easiest oxidation reagents to use are sodium or calcium hypochlorite, while these are often the cheapest one. As a reducing reagent, ferrous sulphate is the cheapest and easiest to use.

Oxidation processes require expert design in order for them to be safe and cost effective.

The most common waste dealt with by oxidation are cyanides from electroplating or case-hardening steel. In order to treat these waste, the easiest and often the cheapest oxidising reagents are sodium or calcium hypochlorite. Other wastes suitable for being treated by oxidation include organic compounds in dilute wastewater *e.g.* phenols, mercaptans, benzidines and unsaturated acids. Oxidation avoids harmful side reactions *e.g.* the formation of chlorophenols.

The most common waste which are treated by reduction are the chromates and chromic acids from chromium plating and tanning industries. The hexavalent ion (Cr VI) which is present in chromic acid is the most toxic and this is reduced to Cr III which can then be removed using alkaline precipitation.

The most commonly used reducing reagent is ferrous sulphate which is obtained from used acids from pickling baths. A combination of sodium sulphite and sulphuric acid is also commonly used.

Many other chemical processes can theoretically be used to treat HW. Some of the more practical include:

- **Hydrolysis:** Certain HW including some pesticides react when getting in touch with water. Hydrolysis causes substances to break down in water and can either be carried out in acid or alkaline conditions. This process should be carried out in very carefully controlled conditions.
- **Electrolysis:**
 - In electrolysis, an electric current is passed through an electrolyte (a solution that contains ions and conducts electricity). This method is used to recover silver from photographic wastewaters. It is also used to treat heat treatment salts containing a high percentage of cyanide.
- **Dechlorination:**
 - Dechlorination is a process where chlorine is chemically removed from chlorinated organic compounds by using powerful reducing reagents. A number of persistent organic pollutants (POPs)



now controlled under the so-called POPs Convention, are chloro-organic materials including long-banned pesticides such as DDT, Dieldrin and Aldrin, and polychlorinated biphenyls (PCBs) which were previously used in electrical transformers and capacitors. Other heavily chlorinated wastes include many solvents used, inter alia, for industrial cleaning e.g. perchloroethylene (tetrachloroethene) or carbon tetrachloride (tetrachloromethane). However, in practice, dechlorination is not regarded as an attractive option because of the very high cost of reagents as well as operational difficulties in their handling and storage. Incineration is still the preferred treatment option, in which case recovery of the chlorine content as hydrochloric acid is an option.

7.2.2.3. Combined physical and chemical processes

As has been stated above, physical and chemical processes are often used in combination. Two common examples where this takes place are:

- Solvent extraction
- Coagulation and flocculation

Solvent extraction can be used to remove selected organic contaminants from wastewaters. During the extraction process, aqueous waste containing dissolved or suspended organic material is mixed with an immiscible solvent which dissolves the organic material. This is followed by a separation stage.

Coagulation is a common method to treat oil/water emulsions such as cutting oils and other water-soluble oils. It involves the aggregation of fine particles from a solution by the addition of coagulants together with high intensity mixing. This is followed by flocculation where the aggregation of coagulated particles combine to form large visible floc particles. Flocculation is improved by gentle stirring. The effectiveness of coagulation and flocculation can be increased by the addition of a physical treatment step, such as sedimentation.

7.2.3. Biological treatment methods

Unlike physical treatment systems biological treatment has the potential to transform organic pollutants into innocuous products rather than merely transferring the pollutant to another medium. Biotreatment is generally cheaper and enjoys a great degree of public acceptance than some other forms of treatment (e.g. incineration). During biodegradation, microbial activity 'recycles' organic molecules. This continuous process is fundamental in biological treatment. Biological treatment processes are well understood and widely used for organic wastes, but mainly non-hazardous ones. However, they are used for some hazardous organic waste, particularly those at low hazardous concentrations. In association with solid waste, biological action takes place naturally within landfill sites and compost processes, and this natural process is encouraged and optimised in biological treatment facilities by control of temperature, nutrient supply and pH.

Different microbial actions take place in aerobic (or oxygen-rich) and anaerobic (or low-oxygen) conditions, while the latter is a common way of treating sewage sludge and animal slurries worldwide. Aerobic degradation can take place over wider temperature and moisture ranges than anaerobic processes, because of the methane bacteria.

Aerobic processes may be open or contained, and in-vessel aerobic systems are increasingly being used for solid waste, but anaerobic treatment is typically used for liquid waste and is carried out in sealed containers or covered lagoons. Many industries with organic waste streams use anaerobic digestion techniques as a pre-treatment stage, to reduce sludge disposal costs (by volatile solids reduction) and to control odours, with – in some cases – the additional benefit of methane collection which can be used to provide on-site energy needs

A brief description of the various biological treatment methods is given below [Adeleke, 2010]:

- **Landspreading and Landfarming.** They are traditional methods used for petroleum sludge disposal. In landspreading, the sludge is evenly dispersed over a plot of land where it can be degraded by native microbial flora over a period of months or years. In landfarming, the sludge is blended into the



soil with tilling equipment, often with the addition of fertilizer to increase the rate of degradation. *The tilling improves aeration and contact of the organisms with the waste.* Landfarming can also be used to biodegrade creosote-containing soils, food processing, pulp and paper, and leather and tanning industries wastes. The major advantage of landfarming and land spreading is the low cost-equipment construction and operation process. However, these methods require a large land area while may be environmentally unacceptable due to the possibility of groundwater contamination, volatile emissions and the long-term accumulation of heavy metals in the soil.

- **Prepared bed reactor.** It is similar to land farming but includes irrigation water systems, nutrient addition, a liner at the bottom of the soil and leachate collection system. Clay or synthetic material is used as liner. The method is often used for contaminants like PAHs, and BTEX (benzene, toluene, ethylbenzene and xylene).
- **Soil piles or Biopiles.** The soil containing the contaminants is *dug up and placed on an impermeable layer* (asphalt or concrete) that retains the contaminated leachate. A perforated piping system is placed in the pile, and air or oxygen is introduced or a vacuum is pulled to enhance aerobic decomposition of the pollutant. A solution containing nutrient and microorganisms may be provided through pipes. Leachate may be collected and recycled through the pile. The pile is covered to contain VOCs, to stabilize the microorganisms' environment, and to control soil erosion. Volatile compounds and gaseous emissions are also collected and treated. Soil piles have been used for the bioremediation of soils contaminated with hydrocarbons, PCP, and the destruction of RDX and HMX in munitions-contaminated soil.
- **Composting.** During composting, the polluted material is mixed together in a pile with solid organic matter that is readily degraded and supplemented with nutrient, air and microorganisms (inoculums) if required. Heat is normally generated during composting which is favourable to biodegradation. The three major types of composting are open windrow, static windrow and reactor system. It has been used to reduce pollutant concentration in soil contaminated with petroleum hydrocarbons, chlorophenols and explosive-contaminated sites (containing TNT, RDX and HMX) [1]. It has also been demonstrated to be suitable for treating toxic heavy oil sludge.
- **Bioventing and Biosparging.** Bioventing involve *introducing air into contaminated soil above the water table*, thereby providing the oxygen needed for the aerobic bacteria to biodegrade the pollutant. The air is introduced by vacuum extraction method, air injection wells, etc. Biosparging is similar to bioventing, but the *air is introduced below water table* (i.e. saturation zone). The purpose is to use the air to transfer the volatile pollutants into overlying unsaturated zone with higher microorganism population. Furthermore, biodegradation will occur in the aquifer [2]. Bioventing is attractive because it operates in situ and because little equipment is required. It has been used for hydrocarbon remediation. It is however not suitable for compounds with high volatility, and soils of low permeability. Biosparging with vapor extraction has been used in sites contaminated with JP-4 jet fuel, and BTEX in soil and groundwater. Ozone (O₃) or steam may also be used in some modification of biosparging to replace oxygen.
- **Phytoremediation.** This is the use plants in the removal or degradation of organic pollutants. This is achieved by the uptake of the contaminants by the plant or by biodegradation by microorganisms in or near the root system of the plant in the rhizosphere (immediate surface of the root and adjacent soil). The reasons for the enhanced biodegradation in the rhizosphere is not yet known but may be due to the larger bacterial mass near the root zone than farther down in the soil. It has the advantage of low cost, but it is only suitable where contaminants are near the surface (1-2m deep). Its use may also be limited where pollutants are strongly sorbed or have become aged or sequestered, where phytotoxicity prevents the plant from rooting extensively, where contaminants leach quickly out of rooting zone, or if the site is oxygen deficient.
- **Bioslurry reactors.** In a slurry-phase treatment system, the contaminated solids (soil, sludge or



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sediments) are mixed constantly with liquid. The operation is similar to activated-sludge process and the biodegradation is extensive because microorganisms' population, temperature, nutrient, oxygen and other conditions can be controlled. It is normally *ex situ* and often more expensive than *in situ* processes. It has been used for the biodegradation of creosotes, 2, 3, and 4 rings PAHs, PCP and dichloromethane while it may be aerobic or anaerobic. Anaerobic bioreactor has been used to treat TNT-contaminated soil. Slurry-phase procedures may be combined with washing technique to treat contaminated soils. The soil is firstly washed to remove the pollutant and the wash solution introduced to the bioreactor.

7.2.4. Thermal treatment processes

The technology for a number of thermal treatment techniques is well-developed and proven, while thermal processing of HW is in common use around the world. The main technologies are often differentiated from one another by the type of grate which is used in the process. Some technologies have been specifically developed to deal with a particular waste stream, while others can handle a broad range of waste types. New thermal techniques are also being developed and refined, including some smaller scale options which may have value in future for HW treatment in many countries. Typically thermal processes have higher capital costs than most other treatment methods, not least because of the high costs of gas cleaning systems which may represent one third of the cost of the facility. The complexity of the technology requires skilled and trained personnel to specify, construct and operate the facilities.

The opportunity to recover materials, heat or energy from the combustion of waste can reduce the operation cost. The location of the facility, and its proximity to markets for heat or power, will dictate the recovery option. There are a number of different industrial processes which use waste as fuel, some for their energy content, others for their minerals or for a combination of the two. These include steel, glass and cement manufacture, but of these, cement kiln use is the most widely applied. Because of the high levels of lime present in cement kilns, the acid components in the flue gases are absorbed, making the co-combustion of HW an effective way of treating (i.e. neutralising) acidic flue gas emissions. Metals are fixed into the cement product.

High operating standards are crucial. Many countries currently have stringent regulations covering the operation and monitoring of thermal treatment facilities, and enforcement of those regulations is an important part of the HW management system. Some of the emissions of concern from thermal processes are extremely small, and their accurate measurement is very difficult. This includes dioxin emissions, which are often cited by opponents as an issue to incineration. Greenpeace has developed international anti-incineration campaign, mainly concerning the dioxin issue. Proper combustion control and gas cleaning measures enable modern plants to meet very strict regulatory limits for dioxins as well as other pollutants. In Europe, dioxin emissions from a number of other industrial processes e.g. steel production, are believed to be far greater than those from modern well-managed waste incineration.

The benefits of thermal processing include the effectiveness of the process for reducing hazard from waste, the energy recovery opportunities as well as volume reduction, given the limited availability of permitted landfill space in some countries.

The term thermal waste treatment is used for all processes in which HW are destroyed by thermal decomposition. This may involve the total or partial waste combustion. Combustion is an oxidation process, generally using oxygen from the air. Combustion temperatures vary depending on the process; for instance the temperature normally reached in a rotary kiln is around 1100°C. There is a distinction between combustion with a lack of oxygen (i.e. incomplete combustion) and complete combustion. Because of the heterogeneous nature of waste, complete combustion requires an excess of air in order to avoid unburned materials, particularly carbon monoxide. During the thermal process, the carbon and hydrogen constituents in waste are transformed into carbon dioxide and water. After combustion, on average 20-35% of waste (by weight)



remains, although the volume reduction can reach 90%, depending on the waste composition and the type/efficiency of the combustion process.

HW incinerators may achieve excellent destruction efficiencies and after scrubbing of the exhaust leave only non-toxic gases to be discharged to the atmosphere; inorganic residues of ash and scrubber sludge to be landfilled; and salt water to be injected in deep wells, evaporated or diluted and discharged. Heavy metals are not destroyed by any process (thermal or other) but thermal process will destroy sulfides and cyanides and leave all metals in the form of metal oxides. Ash and scrubber sludge can be stabilised, solidified or converted to glassy slag which can be safely landfilled [Blackman, 2001].

Some types of waste may require the addition of fuel to achieve complete combustion.

Thermal treatment is suitable for waste with a high carbon and hydrogen content *i.e.* organic wastes. About 20% of industrial waste and 30% of domestic waste is typically incombustible. This includes ferrous and non-ferrous metals such as iron and aluminium. In some cases the first stage of the combustion process is an evaporation stage, where the water is first removed for treatment prior to the actual combustion. Application of thermal processing of HW is constrained by the costs, the need for skilled personnel and the requirements for high operating and safety standards. Safety precautions include a requirement for automatic shutdown of the plant when specified, vital parameters (such as required temperature) are not complied with.

The key factors in order thermal treatment to be acceptable and environmentally sound waste treatment process, include good combustion control and effective flue gas cleaning. These require in turn high capital investment, comprehensive regulation, trained personnel and high operating standards. The complexity of the technology and its need for skilled operation and management result in moderate to high operating costs.

Waste combustion is a well-established and proven process. Experience has shown that the key factors are to maximise combustion efficiency and minimise the formation and dispersal of harmful emissions. The so-called '3 Ts' which influence these factors are the:

- residence time of the waste in the combustion zone, usually recommended as a minimum of 2 sec;
- temperature - at least 850°C;
- turbulence - movement of air in the burner; and
- addition of sufficient excess air.

In order to manage emissions, there are several different flue gas cleaning stages, using filters, adsorbents and gas scrubbers. For HW incineration, which is the most widely used thermal treatment process, a large number of recent technology developments enable good combustion control. These technological improvements are coupled with strict environmental and regulatory controls in many countries.

Waste characteristics- The behaviour of a particular waste type is characterised by its heat or calorific value. That is the amount of heat released during complete combustion. The terms gross and net calorific value (CV) are usually used to describe the heat value. Another important characteristic is the flash point – the temperature at which a flammable waste gives off enough vapour to catch fire when ignited – which must be taken into account in order to avoid the risk of explosions. To ensure proper design of waste storage and fuel feed facilities, the viscosity of the waste is also an important characteristic. For instance, certain fuels such as sludges need to be pumped into the burner.

For the incineration process itself (including the flue gas cleaning) other parameters such as chlorine, fluorine,



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sulphur and heavy metals are important factors requiring analysis.

Combustion Process- Complete combustion requires the addition of excess air to ensure sufficient air throughout the combustion process, as well as turbulence, a suitable residence time and the correct temperature. Mechanical mixing of waste is also necessary, and during combustion this may be achieved for example by the movements of the incinerator grate. Mixing of waste before fed into the furnace may also help in ensuring even distribution and aeration. Waste behaviour during combustion varies according to its heat value and form. Certain waste change their physical characteristics during combustion e.g. some solids become liquids. The igniting of gases and liquids given off by the waste as it combusts can cause problems for plant operators in regulating the process, and can also damage equipment.

By-products of incineration - The by-products of incineration may be solid or liquid including flue gases, slag and ash as well as the products of the flue gas treatment (sometimes called air pollution control (APC) residues) plus wastewater. The three types of solid residues from incineration are: the bottom ash or slag, the fly ash and the air pollution control (APC) residues. The terms used to describe these three waste types differ between countries but typically:

- Bottom ash or slag is the solid combustion residues from combustion
- Fly ash is the fine air-borne ash *e.g.* which collects under the combustion chamber or boiler, in the electrostatic precipitators or other dust collection systems
- APC residues are the wastes (*e.g.* spent lime) created in the treatment and cleaning of emissions

The regulations concerning the disposal of these three waste differ between countries. For example, national regulations may classify the fly ash as a HW requiring treatment prior to disposal. The bottom ash may be landfilled or, often, used as an aggregate substitute *e.g.* for road building.

The amount and type of pollutant in the emissions from thermal processes depend on the pollutants in the waste, the technology and the efficiency of its operation. The current methods of incinerating waste generate on average between 6 and 7 normal cubic metres of flue gas for every kilogram of incinerated waste. This varies according to a number of elements, including the chemical composition of waste themselves. Regulatory controls on emissions from incineration have been strengthened in recent years in most countries. For example, the legal thresholds in the European Union have been divided by more than 100 in 20 years, and the emission limit for dioxins is now 0.1ng TEQ/Nm³ (where TEQ represents an agreed toxic equivalent). These stricter regulations have required major changes in technology and operating practices, and greatly increased the costs of waste incineration.

To comply with the new limits for dust a number of stages are required. This may include the use of electrostatic precipitators (which alternate high voltage discharges of ionising wires with earthed collection



plates) as well as fabric filters which trap the dust.

It is necessary to neutralise the chlorine with calcium (usually in the form of lime) or sodium hydroxide in one of several alternative treatment systems: dry, semi-dry, semi-wet or wet scrubbing. The latter is the most efficient among all but has higher equipment costs and leaves a larger liquid residue which (due to its low pH) needs to be neutralised before discharge.

A significant part of the sulphur is eliminated with chlorine but in order to comply with emissions limits it is probably necessary to add a washing stage with a higher pH than the first wash. This adds to the complexity of the total process because – like every other wet treatment – it imposes additional equipment needs and reagent conditions as well as leaving a liquid residue for treatment and disposal.

Dioxins-

Where waste combustion is incomplete, or the process is not well managed, a number of unwelcome by-products may occur. such as dioxins. Dioxins are widespread in the environment through waste and as trace amounts in all combustion processes, from power plants and diesel vehicles to forest fires and garden barbecues. The 3Ts help to ensure the destruction of dioxins from waste, and to limit the reformation of dioxins as the cooling gas stream leaves the combustion zone. The further practice of reducing the time combustion gases spend in the critical temperature range, and limiting contact with fly ash, helps reduce dioxin reformation. However, permitted levels of dioxin emission are extremely low in many developed countries, so in addition to careful combustion control, further gas cleaning procedures may still be needed to ensure compliance. This involves passing the flue gases through activated carbon. The activated carbon filter is also a polishing stage for the elimination of mercury.

Wastewater from incineration- Control on wastewater vary from country to country. The wastewater from flue gas cleaning is normally treated in a separate wastewater treatment plant. Treatment of wastewater in aerated lagoons is a widely used and low cost option but this may not meet the required standard and physical-chemical treatment is generally needed prior to the biological stage. The less wastewater generated *e.g.* by use of dry or semi dry flue gas scrubbing techniques, the lower the facility's equipment and operating costs.

Measurement- In addition to ensuring proper operating conditions, requires regular (or continuous) measurement of the controlled parameters. In many countries the measurement and reporting of these parameters is a required part of the permitting process for facilities. Guaranteed standards may be imposed. However, there are some difficulties listed following:

- Measuring equipment may be imprecise
- Errors may be made due to the need for correlation of numbers. For example, the dust contained in the gas is not measured, but rather the opacity resulting from its presence or the number of particles may be measured by light absorption. Errors of correlation are more significant when the material being measured is small.
- Errors may also be made in sampling. The sample analysed is always very small compared to the total gases generated – a few cubic centimetres of gas or liquid compared to several cubic metres for liquids and thousands of cubic metres for gases. The sample may not truly represent the total residue



stream while this is significant when the figures are small.

The level of inaccuracy can be quite high: for example, 30% for dust and 40% for chlorine. This must be taken into account by the operator and by the inspector or regulator when considering compliance.

Costs- The high level of sophistication and control associated with thermal methods of waste treatment are reflected in the high costs of constructing such a plant. Once built, treatment costs per tonne may not differ greatly from other technologies, but all costs are related to a number of site specific and country specific factors and cannot be estimated here. The costs of air pollution control systems represent a substantial proportion of the cost of a new facility, and may be 30-40% of the total. It is worth noting that the volume, weight and hazard of waste remaining for final disposal are greatly reduced, a valuable point when treatment or disposal capacity are limited. The recovery and sale of energy from the process improves overall costs.

Characteristic examples of combustion technologies are hereafter presented:

- **Rotary kiln incinerator-** Rotary kiln incinerators are extensively used because of their ability to handle a wide variety of HW. The average plant capacity is 25,000-50,000 tonnes per year. Waste may be in the form of solids, liquids or drummed waste. Solid and drummed waste are sometimes shredded before they are fed through the conveyer system. Pumpable sludge and liquids are injected through a nozzle. The kiln is operating at around 1200oC and the off-gas from the first chamber is combusted afterwards (at around 1000oC) in the secondary chamber to reduce particulates and ensure complete destruction of hazardous components. From the secondary chamber the hot gases are transferred to a waste heat boiler which produces steam. The slag's long residence time of approximately 30 minutes is necessary because the temperature in the solid bed of the kiln is not uniform. Wet or dry scrubbers are used to treat the flue gases, with any fluids from the gas scrubbing process being treated. Sludge is sent for sedimentation and dewatering, and in some countries for additional processes such as activated carbon filtration. A 50,000 tonnes per year facility might generate around 10,000 tonnes of slag, 1,000 tonnes of fly ash and 150 tonnes of dewatered sludge per year. The disadvantages of rotary kiln furnaces include their high capital, operating and maintenance costs and the need for trained operators.
- **Fluidised bed combustion-** Fluidised bed combustion is suitable for a variety of HW, whether they are solid, liquid or gaseous. The technology enables the operator to control residence times and sustain stable temperatures, while it has good gas-to-solids contact characteristics. It operates at temperature ranging from 650 to 775oC. Highly persistent chlorinated hydrocarbons may be destroyed by this technology. Types of fluidised bed incinerators include bubbling fluidised bed incinerator and circulating fluidised bed incinerator.
- **Pyrolysis-** Pyrolysis is a partial combustion process which takes place in a closed container in the absence of oxygen. Because waste treated by pyrolysis are imperfectly oxidised they still exhibit a LHV. The manufacture of charcoal is an example of a pyrolysis process, which has been used for many years. Products of pyrolysis include combustible gases, a solid product in the form of a char (similar to charcoal) and a mixed residue of oils and other liquids. The char can be upgraded to a fuel with similar heat value as low grade coal, and the liquid effluent is treated before discharge. Where the oil is present in sufficient quantity it can be refined for use, otherwise it may be returned to the reactor for gasification. The advantages of pyrolysis include the fact that the operating temperature is lower (never exceeding 500oC), and the process does not need the addition of excess air. This also results in less flue gas, which can be re-used. In addition, the by-products from pyrolysis are combustible. The disadvantages of pyrolysis include the fact that the operating temperature depends on the nature of waste. A low temperature may cause unstable reactions during waste treatment.. Setting the



temperature too high can result in complete combustion, which cancels the advantages of incomplete combustion. Achieving a stable process is very difficult, because of the variability of the waste. Pyrolysis is only used for specific waste streams, and is not often used on a large scale. Pyrolysis is not as widely used for waste treatment as other combustion processes, and is not commonly used for mixed HW. However, pyrolysis is successfully used on a small scale in some countries e.g. USA, UK for single waste streams such as scrap types and waste plastics. Pyrolysis is also used for pre-treatment of health-care wastes, and for treatment of contaminated soils. Pre-treatment of health care waste – which mainly consist of materials such as bandages, organic material, plastic (e.g. safety clothes, syringes, tubes etc) – is effective because of their relatively homogeneous nature. A temperature of 300oC is sufficient to ensure good hygiene and the gaseous by-products can be re-injected to support the reaction. The solid by-products, which are now sterilised, can be incinerated in municipal solid waste incineration plants. Pyrolytic treatment of contaminated soils enables the distillation of organic pollutants (hydrocarbons, tar etc) leaving a sterile solid by-product which can usually be landfilled. Depending on the heavy metal concentration, stabilisation could be required prior to landfilling. The gases can be used to support the reaction or alternatively to heat the waste soil before introducing it to the reactor

- **Gasification-** Gasification is a partial combustion process with some similarities to pyrolysis but it takes place in an oxygen atmosphere. Unlike in complete combustion, excess oxygen is not supplied. Oxygen, steam and the fuel (e.g. HW) are injected through nozzles in the hearth zone of the gasifier. This process offers highly efficient destruction of HW at lower temperatures than an incinerator. Thermal destruction is ensured by a combination of high-temperature oxidation followed by high temperature reduction. By-products of gasification are useful gases e.g. hydrogen, methane and sometimes a solid char, depending on the process. Like pyrolysis, gasification is not widely used for waste treatment.

7.2.5. Energy recovery

Waste combustion always produces heat. In order to enable energy recovery to be achieved, waste must have sufficient heating value to reach appropriate combustion temperatures without the need for additional fuel. Therefore the minimum heating value of a waste for incineration with energy recovery depend on the operating temperature.

Energy recovery is typical via the production of steam which is driven through a turbine to produce electricity. If the steam cannot be further used (*e.g.* for a neighbouring factory or for the production of distilled water), it must be condensed before being reintroduced into the system. In this case, the amount of heat recovered will not exceed 35% of the heat produced because of condensing losses. Where it is possible to use the energy or (better still) the heat given out by the condensation stage (*e.g.* in dryers or central heating), it is possible to reach and even exceed 90% efficiency. The recovery percentages will not depend on waste or the method of combusting it but rather on the opportunities to sell low-grade heat as well as energy. The opportunities for large sales are faced to be improved where facilities are built in industrial areas.

In addition to the sale of surplus energy whenever possible, the recovery of energy is beneficial to waste incinerator operator because it can be used for in-house demands and savings can be made on fuel costs to run the facility.

A number of industrial processes use waste as a fuel or as a constituent part of the product. These include combined heat and power plants, glass furnaces, steel manufacturing, lime and cement kilns. The option to use a cement kiln for the thermal treatment of hazardous organic wastes can be technically and environmentally sound. These types of kilns have been used extensively for more than 20 years for HW



treatment both in developed countries and in developing economies.

The typical combustion conditions include temperatures in the range 1,350-1,650°C, with a long gas phase residence time of up to 10 seconds or more and strong turbulence in the kiln, so that complete destruction is virtually assured. The alkaline environment in the kiln absorbs and neutralises most of the acid gases and metals. Non-volatile heavy metals are fixed into the clinker's crystalline structure. The vacuum operation of the kiln provides little or no outward leakage of fumes. The huge thermal inertia prevents rapid temperature excursions. The quality of the cement product is relatively insensitive to most trace elements and impurities from waste. The kiln also allows the recovery of substantial amounts of energy present in certain kinds of organic wastes, thereby replacing primary fuel and potentially fees for treating the waste. As cement production is highly energy-intensive (40-65% of total cost), the saving in primary fuels makes the burning of organic wastes attractive from the kiln operator's point of view.

Many multinational cement companies have developed considerable expertise in co-combustion of HW in cement kilns. However, the first priority of the operator must remain the production of cement. It is thus likely the blending of the organic waste will need to take place at a centralised HW treatment facility, with the blended fuel being sent to the cement kiln. The basic components of this fuel are likely to be waste oils and solvents; these high CV and less viscous wastes can be used to dilute heavier organic sludges and tank bottoms to make them suitable for pumping into the cement kiln. It may be possible to blend small quantities of solid waste such as pesticides and waste pharmaceuticals by first macerating it.

Modifications may be necessary to allow the environmentally acceptable co-combustion of HW. The process is focused on the need to control waste input and to ensure effective combustion. A separate, dedicated waste feeding system will generally be required. Automatic temperature control systems and gas monitoring will also be necessary. Liquid, solid and sludge wastes can be processed in this way, with some cement facilities transforming sludge and solid wastes into a homogeneous pumpable fuel suitable for injection into the process along with liquids. A wide range of waste types can be treated, from oily wastes, wastewaters, sludges from wastewater treatment, solvents and organic compounds.

Some waste types are not suitable for co-combustion in cement kilns e.g. highly contaminated waste, and waste with a high water, chlorine, heavy metals or sulphur content.

The benefits of cement kiln combustion of HW include the moderate cost due to the existing process. Additionally, there is a net decrease in fossil fuel use and no generation of by-products. However, there are costs associated with the need for fuel preparation and fuel feed adaptations, and there may be concerns - as well as extra costs - associated with the health and safety aspects of handling HW. For example additional dust controls and gas cleaning measures may be required.

7.2.6. Disposal

HW disposal practice has historically followed the path of least resistance. Several factors have driven HW onto and beneath the earth's surface. These factors include (1) the relatively low cost of land and land disposal procedures; (2) the environmental legislation of previous years which placed stringent controls on releases to the atmosphere and to 'waters of nation'; and (3) widely held beliefs to the effect that land disposal was safe and proper.

The tragic consequences of these practices are now upon us in the form of several thousand contaminated sites in various stages of remedial activity, some of which cannot be cleaned up; tens of thousands of 'brownfields' that will receive minimal if any remediation; more than 6,000 contaminated sites in Eastern Europe; untold thousands of sites elsewhere in the world; and contaminated groundwater, estuaries, and bays coinciding with irresponsible land disposal of HW in countless sites around the world.

'Sanitary landfills' were developed for the disposal of municipal refuse as an orderly alternative to the open



dump. Design and operating procedures have evolved to include elaborate safeguards against leakage and migration of leachates. Most sanitary landfills do not knowingly accept HW. Secure landfills for HW disposal are now equipped with double liners, leakage detection, leachate monitoring and collection and groundwater monitoring systems. Synthetic liners are of minimum 30 mil thickness. Liner technology has improved greatly and continues to do so. Very large sections of liner fabric minimise the number of joints. Adjacent sections are 'welded' together to form leak-proof joints having a high degree of integrity. Liners are protected by sand bedding of finer material devoid of sharp edges or points which might penetrate the liner fabric. Another layer of bedding protects the inner liner from damage by machinery working the waste. The completed liner must demonstrate permeability of less than 10⁻⁶ cm/sec and must include a leachate collection system.

Leachate detection and collection systems are equipped with access to sumps via galleries, pumps or other means of leachate sampling or removal. The double liner, leachate detection and leachate collection systems are diagrammed in figure 10.

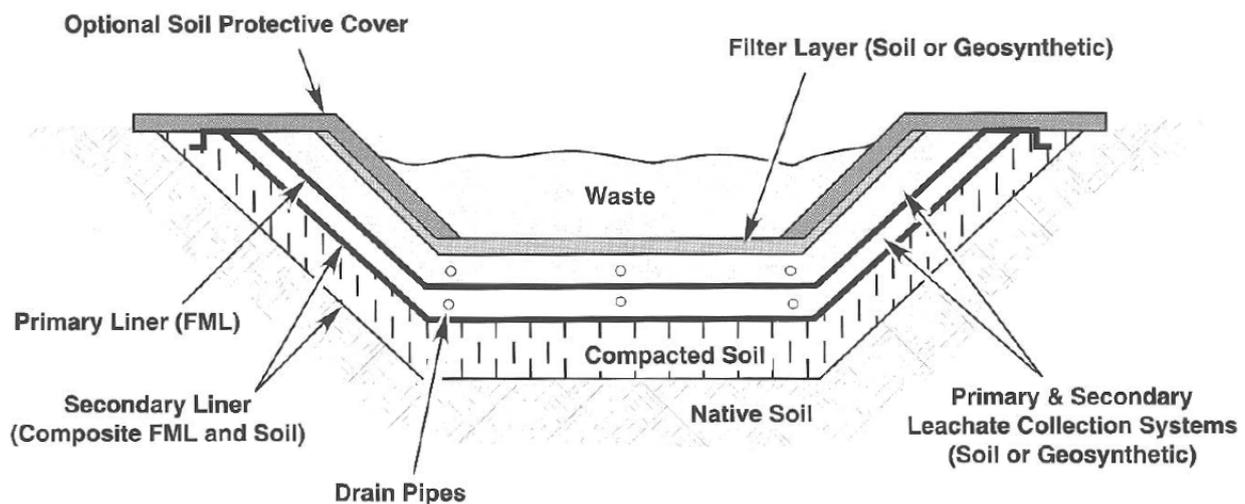


Figure 10. Cross section of a secure landfill double-liner system.

Landfills have historically presented two general classes of problems. The first of these includes fires, explosions, production of toxic fumes and related problems from improper management of ignitable, reactive and incompatible waste. Owners or operators are required to analyse their waste to provide enough information for proper management thereof. They must control the mixing of incompatible waste in landfill cells. They may landfill ignitable and reactive waste only when the waste meet all applicable requirements of the land disposal restrictions and have been rendered un-ignitable or non-reactive. Placement of bulk or non-containerised liquid HW or HW containing free liquids in any landfill is prohibited¹. The second general class of landfill problems concerns the contamination of surface and groundwater. HW landfills must have double liners, a leachate detection and removal system (LDRS) which must drain into a sump where an approved action leachate rate (ALR) is measured. It is required diversion of run-on away from the active face of the landfill; treatment of any liquid waste or semisolid waste so that they do not contain free liquids; and proper closure (including a cover) and post-closure care to control erosion and the infiltration of rainfall. Unless they are very small (such as ampoules), containers placed in landfills must be at least 90% full or be crushed or otherwise reduced in volume, in order to prevent voids and collapse of final landfill covers. Groundwater monitoring is required as is the collection of rainwater and other run-off from the active face of the landfill. Segregation of waste such as acids that could mobilise, solubilise or dissolve other waste or waste constituents is required. Extensive monitoring and inspection requirements are imposed throughout the active life of the landfill and

¹ In certain situations small containers (such as ampoules placed in lab packs) holding free liquids may be landfilled.



during the closure and post-closure periods.

8. HEALTH AND SAFETY IN HW GENERATION SITES

Industrial hygienists can be extremely helpful to workers by identifying, evaluating and recommending controls for health hazards on the job. Experience has shown, however, that industrial hygienists' personal exposure monitoring and exposure limits have been used to "scientifically prove" that working conditions are "safe" when they were not, even when workers were getting sick. The idea of measuring how much of a chemical, radiation, noise or other hazard a worker is exposed to and comparing this to a level that has been proven to be safe is not a bad idea. But there are many problems with the way this has worked in practice [Senn, 2003].

- *Problem I:* Most chemicals and other hazards have not had adequate long-term tests conducted to determine whether they can cause cancer, damage brain and nervous system function, lung function, immune and hormone systems function, reproductive system function or many other vital body functions.
- *Problem II:* Legal or recommended limits are often thousands of times too high to protect health. Many limits were set using unscientific, irregular procedures and corporations have strongly influenced or even dictated the outcome.
- *Problem III:* OSHA tried to "update" its PELs in 1988. However, it did not use the latest scientific methods or information to do so, and the new PELs were only slightly more protective than the old ones. The new rule was remanded by the U.S. Circuit Court of Appeals and these limits are not currently in force.
- *Problem IV:* Most measurements of worker exposure have been incomplete and inaccurate.
- *Problem V:* Industrial hygienists' preoccupation with the ritual of air sampling has given the impression that this is the best way to approach an occupational health problem and detracted from other, more useful activities that industrial hygienists can perform such as evaluating controls.

In sites where HW is generated the worker health and safety is under concern. As there is a great variety of possible or potential hazards existent, such as

- *Chemical exposure* due to inhalation, absorption, ingestion or injection of chemicals.
- *Explosion and/or fire*
- *Oxygen deficiency* if air is depresses to 16%
- *Ionising Radiation* if α , β or γ radiation is present.
- *Biologic hazards* (in healthcare institutions) if medical and infectious waste are encountered on-site.
- *Bloodborne Pathogens* (in healthcare institutions) of injury by contaminated needles and other sharps.
- *Safety Hazards* due to sharp objects slippery surfaces, underground storage tanks being lifted or positioned, etc.
- *Electrical hazards* due to overhead power lines, downed electrical wires and buried cables.
- *Heat stress* when workers are wearing protective clothing (to shield the body from chemical exposure) which limits the dissipation of body heat and moisture.
- *Cold exposure*
- *Noise hazard* due to heavy equipment and machinery.
- *Other physical hazards* such as vibrations, misused or malfunctioning hand tools, fall from heights, etc.

9. PERSONNEL TRAINING

As it can be shown from the above, industrial hygiene often has misplaced an emphasis on technical sampling



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methods rather than good investigations into health hazards (c.f. Table 7) and innovative problem solving. The more we realize that the best industrial hygiene is problem-solving, the more accessible it is for union health and safety representatives and activists. Here is a review of the traditional concepts of industrial hygiene and how a labor union might approach them.

- **Hazard Recognition:** The best way to recognize potential health hazards is to know work operations and the associated hazards in the particular workplace. Inspections that utilize visual observations of the workplace for those hazards and talking to the “experts” (workers) are the best ways to learn the hazards.
- **Hazard Evaluation.** This currently is done by sampling. Instead, evaluation can be performed by observing visible contaminants, noting odours, predicting exposure from situations such as open containers or spraying operations, or from interviewing workers about their health symptoms and complaints.
- **Controlling Hazards.** This requires problem-solving techniques, coupled with solutions. Some solutions, such as designing a ventilation system, require a certain amount of technical expertise, while others require job expertise to recognize ways to change work organization and work practices. All solutions need to be trial-tested and modified until they are workable.

Table 7. Overview of Typical Hazards encountered at hazardous waste sites [Martin et al., 2000].

Hazard type	Exposure route or cause	Symptom or effect	Measurement or measuring device	Prevention	Personal protection	Additional Comments
Chemical exposure	Inhalation, eye/skin contact, ingestion, puncture	Headaches. Nauseas, rashes, burning, coughing, cancer, liver damage. Kidney damage, convulsions, coma, death.	TLV, PEL, IDLH, LD ₅₀ , etc. Devices: OVAs, HNU, air sampling, detection tubes, personal monitoring, field GC.	Follow SOP and safety procedures: use extra caution when working in hot zones. Use remote control devices whenever possible.	Protective clothing. Respiratory protection	Remove person immediately and decontaminate if exposed to chemical.
Ionizing radiation	Molecular degradation releases gamma. Beta and alpha radiation: gamma is more serious; alpha is most hazardous in case of ingestion.	Radiation burns, mutagenicity, death	Radiation detection meters. Geiger-Muller detector, gamma scintillation meter	Do radiation survey early investigation. Gamma is detectable through thin metal (e.g. drums) so survey can be done without disturbing chemical wastes.	Protective clothing and dust masks will protect against alpha and help limit beta. Only limited protection against gamma is available.	Consult health physicist if measurements are above 10mR/hr. At 1mR/hr beck off and map the 1 mR/hr area.
Fire and explosion	Unstable chemicals; incompatible reactions; shock ;sensitive chemicals; vapour building in enclosed spaces or low-lying areas with sparks, open flames or static electricity	Burns, concussion, shock, dismemberment, death.	Flash point<100°F- flammable material, 100-200°F-fire hazard. Explosimeter>25%LEL- withdraw and re-evaluate situation; will not read accurately in oxygen-deficient environment >10% LEL- stop all spark producing operation.	Ventilate to prevent vapour build-up; use only nonsparking tools; use explosion proof or intrinsically safe instruments	Nomex. Fire proximity suits. Blasts suits SCBAs.	Always test chemicals before mixing; in closed areas, use a nitrogen blanket. Generation of toxic vapors and fumes may result in chemical exposures.
Oxygen deficiency	In enclosed spaces (e.g. buildings, tanks, manholes) or low areas (e.g. trenches) oxygen is replaced by other gases; generally they are dangerous toxic gases and vapors.	Inattention, impaired judgement, reduced coordination, altered breathing and heart rate, nausea, brain damage, unconsciousness, death.	21% O ₂ is normal. <19.5% O ₂ is of concern at HW sites. <10% O ₂ is dangerous to humans. When O ₂ is displaced in air N ₂ is displaced also. They are in a 4:1 ratio.	Monitor enclosed and low areas before entry; use mechanical ventilation	SCBAs supply air. Safety lines.	When O ₂ is below 19.5% at HW site assume O ₂ has been replaced by toxic gases or vapors. Toxic gasses will likely require protective clothing as well.

Hazard type	Exposure route or cause	Symptom or effect	Measurement or measuring device	Prevention	Personal protection	Additional Comments
Cold exposure	Caused by difficult work done in clothing designed to protect against chemicals but not against weather conditions.	Frostbite pulled muscles, reduced coordination, hypothermia, death.	Temperatures, both ambient and body	Frequent rest breaks, monitor body temperature and condition, drink fluids, appropriate clothing for weather conditions.	Warm clothing under cold conditions	Beware of cryogenic chemicals
Biologic (etiologic) hazards	Waste from hospitals and research facilities	Fever, disease, death	Swab, swipe and grab high-volume air samplers using liquid impingement media. Requires laboratory incubation and identification. No direct measurement available.	Decontaminate with disinfectant and use good personal hygiene, immunise if agent is known.	Disposable gloves	Biohazard label should result in presumption of etiologic agents present until additional data obtained. Hospital waste (e.g. needles, bloody bandages, surgical tubing) should be considered suspect.
Noise	Compressors, machinery, large equipment	Temporary or permanent hearing loss, aural pain, nausea, reduced muscular control (when exposure are severe), distraction and interference with communication	Should level meter and octava-band analyser	Shielding or enclosure of source. Distance/isolation. Substitution of equipment/machines generating less noise.	Earplugs	Use of earphones with communication built in can improve coordination and warnings. Use of earplugs must include consideration of potential indirect exposures if earplugs become contaminated.



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ACRONYMS

DDT	DichloroDiphenylTrichloroethane
EPA	Environmental Protection Agency
GHG	GreenHouse Gases
HHW	Household Hazardous Waste
HW	Hazardous Waste
LOAEL	Lowest Observable Adverse Effect level
NIMBY	Not-In-My-Back-Yard
NOAEL	No Observable Adverse Effect Level
OECD	Organisation for Economic Cooperation and Development
POP	Persistent Organic Pollutants
PWB	Printed Wiring Board
RCRA	Resource Conservation and Recovery Act
TCLP	Toxicity Characteristic Leaching Procedure
TSDF	Treatment, Storage and Disposal Facilities

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